TECHNICAL REPORT TD-77-8

RADIO FREQUENCY SIMULATION SYSTEM (RFSS) CAPABILITIES SUMMARY

Aeroballistics Directorate
Advanced Simulation Center

April 1977

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US Army Missile Research and Development Command
Redstone Arsenal, Alabama 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Advanced Simulation Center's Radio Frequency Simulation System is employed in hardware-in-the-loop simulation and evaluation of sensors, guidance and control subsystems of radar-guided missiles in the 4 to 18 GHz frequency spectrum. The Radio Frequency Simulation System facility is an operating element of the Advanced Simulation Center, Aeroballistics Directorate,

ABSTRACT (Continued)

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ABSTRACT (Concluded)

US Army Missile Research and Development Command, Redstone Arsenal, Alabama. The facility provides a computer-controlled multiple target array of 534 antennas and an electronic countermeasures of 16 antennas (with an associated feed system and radio frequency generation system). Two three-axis flight tables and an aerodynamic loader are provided to simulate the dynamic environment of a missile in flight. The simulation electromagnetic environment includes line-of-sight angles (target position), polarized target signatures, electronic countermeasures, clutter, multipath, glint, and scintillation phenomena. Simulation and testing determine seeker characteristics such as tracking accuracy and engagement parameters such as miss-distance statistics.

Block 19 (Concluded)

Radio frequency missile guidance simulation
Open-loop simulation
Closed-loop simulation
Real-time critical simulation

CONTENTS

FOREWORD

This document provides the potential user of the Radio Frequency Simulation System with a summary of the capabilities of the Radio Frequency Simulation System for assessing the facility's suitability to his specific program and introduces him to the Army's Advanced Simulation Center. A more detailed discussion of the design and capabilities of the Radio Frequency Simulation System is provided in the Radio Frequency Simulation System Design Handbook, D243-10004-1, Revision A, 10 March 1976. The operational policies of the Radio Frequency Simulation System and a description of how a typical program is implemented by the combined Radio Frequency Simulation System and user team are provided in the Radio Frequency Simulation System User Orientation and Operation Summary.

The US Army's Advanced Simulation Center consists of a centrally located, modern, hybrid computer complex surrounded peripherally by three environmental physical effects simulators. The Infrared, Electrooptical, and Radio Frequency Simulation Systems are capable of spectral bandwidths and physical motions required for the evaluation of a wide variety of guidance systems and components. Under central computer control the physical effects simulators (both open- and closed-loop) provide real-time simulation capability, thus permitting precise and repeatable measurements of guidance system performance characteristics in nondestructive tests.

The infrared simulation system is a simulation tool for the design, development, and evaluation of infrared sensor systems applicable to surface-to-air, air-to-air, and air-to-surface missiles. Sensors in the 0.2- to 0.4- and 1.0- to 5.0-μm bands are hybrid computer controlled in six degrees-of-freedom during the target engagement sequence. A gimballed flight table provides pitch, yaw, and roll movements to the sensor airframe. A target generator simulates a variety of target/background combinations which includes tailpipes, plumes, flares, and fuselages in single or multiple displays against clear, clouded, overcast, or sunlit sky. These are then displayed in azimuth, elevation, range, and aspect by the target projection subsystem through a folded optical network, a display arm, and a display mirror. Simulation capability ranges from open-loop component evaluation to closed-loop total system simulation.

The electrooptical simulation system provides realistic and precisely controlled environments for the nondestructive simulation of a wide variety of ultraviolet, visible, and near infrared sensor systems. Actual sensors are hybrid computer controlled in six degrees-of-freedom while viewing targets under controlled illumination levels

(10^{-4} to 10^{3} foot-candles) in an indoor simulation chamber, and under ambient conditions on an outdoor simulation range. Three-dimensional target simulation is provided on a 32- × 32-ft terrain/target model/transporter which features a variety of topographical and man-made complexes at 600:1 and 300:1 scales, removable model sections, and fixed and moving targets at any desirable scale. A moving projection subsystem provides two-dimensional representation. A gimballed flight table capable of simulating pitch, yaw, and roll movements to the sensor airframe is attached to a transport which moves vertically and laterally. The terrain/target model or the two-dimensional projection subsystem is moved toward the flight table to provide the sixth degree-of-freedom. An adjacent high resolution TV/joystick console and proposed helicopter crew station provide a means of evaluating man-in-the-loop guidance and target acquisition concepts.

I. INTRODUCTION

The Advanced Simulation Center's (ASC) Radio Frequency Simulation System (RFSS) is designed to enhance missile system research, development, and engineering capabilities through cost-effective simulation of high performance missiles in realistic engagements. Realistic engagement scenarios include the use of jamming signals generated by actual jammers in the loop, multiple targets, and the simulation of clutter, multipath, glint, and scintillation phenomena. Additionally, missile-target trajectories which exceed the performance of today's aircraft can be readily simulated. The primary application is hardware-in-the loop (HWIL) simulation of passive, semiactive, active, command, beam rider, and track-via-missile (TVM) radar terminal-guidance systems for surface-to-air, air-to-air, air-to-surface, and surface-to-surface engagements. The ASC is particularly cost-effective in test series involving large parametric variations where a large number of runs is required in a controlled environment. One program, for example, has accomplished 3000 flight engagements of realistic deceptive jammer evaluation against a semiactive seeker in three weeks of testing.

An equally important application of the ASC is to bridge the gap between analytical missile simulations and flight test programs. After partitioning of the missile elements in a simulation program, the ASC can be used to evaluate and validate any combination of the analytically partitioned elements with flight hardware counterparts. Statistical data can be obtained and analyzed rapidly to verify the analytical models and to collect data to augment or optimize flight test programs.

Simulation in the RFSS is accomplished by radiating at operating wavelengths to actual seeker hardware functioning in a dynamically simulated missile-target engagement. Four independent targets can be generated and displayed simultaneously in the 4- to 12-GHz range and two targets in the 12- to 18-GHz range. The targets, controllable in target signature, range, and angular motion, are provided by a computer-controlled RF generation system and a 534-element array of antennas. Target signature control includes Doppler, range delay, polarization diversity, pulse duration, chirp, etc. Two additional denial electronic countermeasures (ECM) channels feed 16 ECM array antennas distributed among the target antennas to display two ECM signals in the ranges cited previously for simulating stand-off jammers (SOJ) that are slow moving with respect to the engagement geometry. ECM signals, generated by actual jammers or by the RF generation channels, can be dynamically colocated on the target signal through the use of a separate target channel to simulate an on-board self-screening or deceptive jammer. In this sense, the two RF generation ECM channels can also be used to simulate broadband, on-board jammers in a self-screening mode. Ejectable and escort screening jammers (ESJ) can be simulated in a similar manner with separate dynamic trajectory control.

The missile-target trajectory is accomplished through a combination of target motion provided by the antenna array and autopilot and guidance-sensor motion provided by the two three-axis rotational flight simulators. Aerodynamic loads are simulated using an aerodynamic loader acting on the missile elevons. An artist's concept of the RFSS facility and a tactical air-defense scenario that can be simulated in the facility is shown in Figure 1. The location of the RFSS within the McMorrow Laboratories are shown in Figure 2.

The ASC facilitates the following research, development, and engineering activities:

a) Analytical and HWIL simulation support of missile systems throughout their life cycle.

1) Evaluate breadboard and brassboard performance.

2) Evaluate basic designs and design modifications.

3) Establish optimum values for subsystem performance parameters.

4) Determine missile subsystem performance bounds.

5) Optimize captive and flight test programs by pre- and post-flight analysis, minimize flight test failures, and provide evaluation for scenarios where flight programs are not feasible or cost effective.

b) RF seeker hardware simulation at microwave frequencies to define and analyze nonlinear processes in sensor hardware.

c) Performance envelope mapping (miss-distance statistics) against a multiplicity of scenarios to increase the level of confidence in fielded missile systems.

d) Exploitation of acquired and/or fabricated foreign missile systems.

e) Conduct ECM and electronic counter countermeasures (ECCM) analyses and vulnerability studies.

f) Explore clutter, multipath, polarization, glint, and scintillation effects.

A. ASC General Capabilities and Applications Using the RFSS

Open- or closed-loop simulation may be conducted with various missile hardware elements simulated or with various elements of the HWIL. Closed-loop simulation requires that all elements of the missile system be included. It should be noted that all elements of the missile system need not be present in hardware form because they may be modeled mathematically in analog or digital computers. In open-loop simulation, the guidance loop is not closed. For example, open-loop

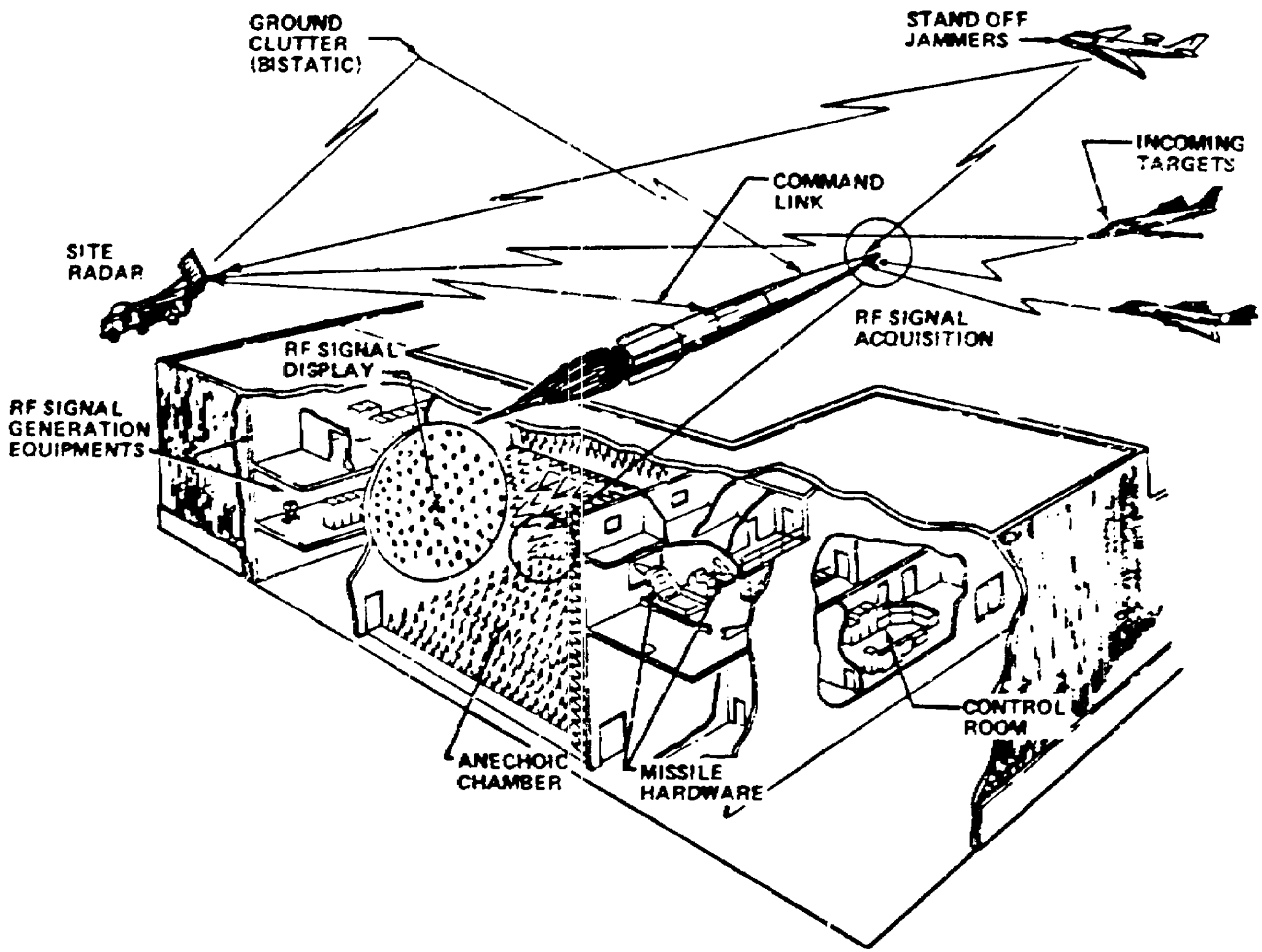


Figure 1. MIRADCOM Radio Frequency Simulation System.

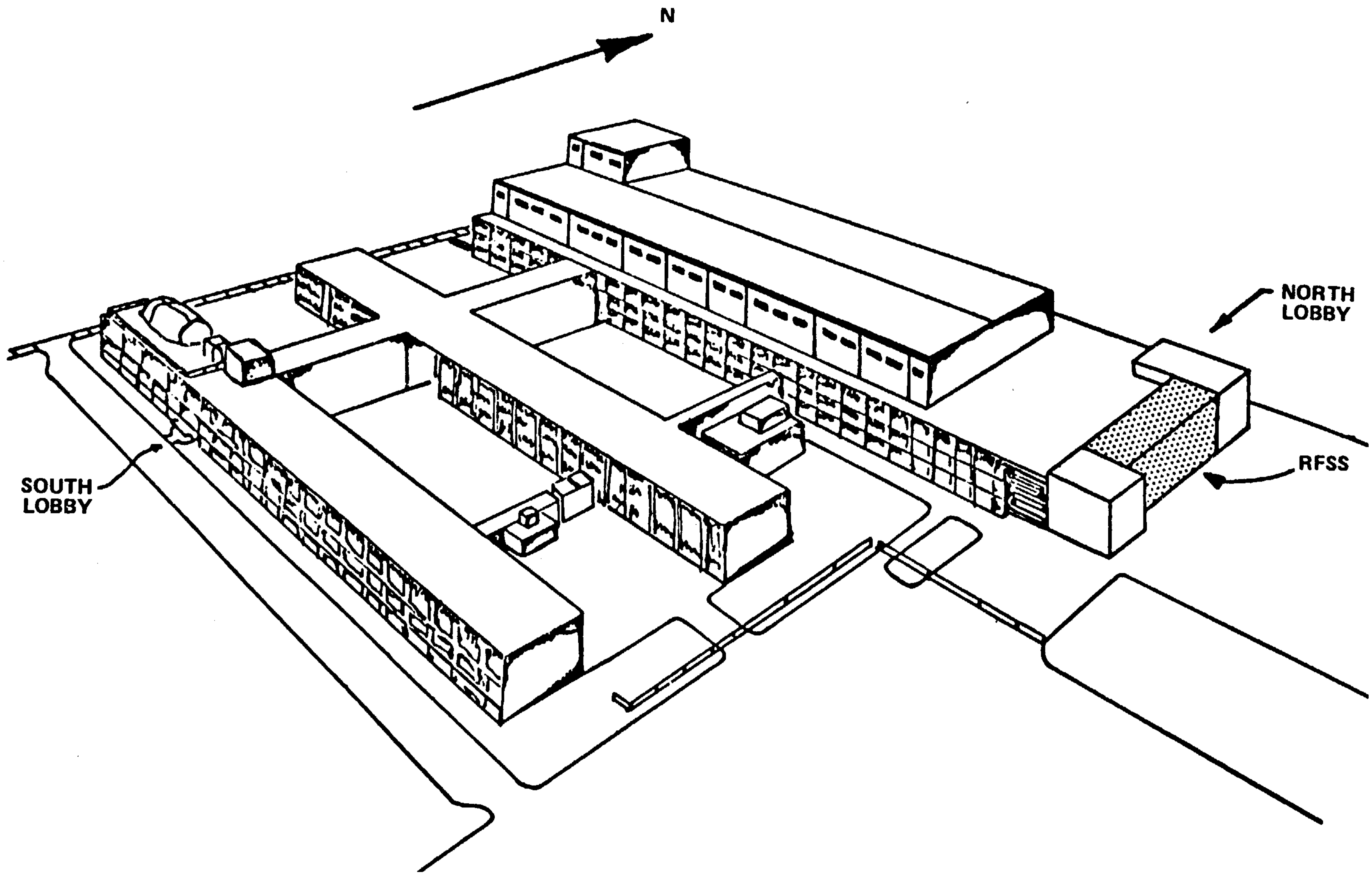


Figure 2. Francis J. McMorrow Missile Laboratories.

simulation is performed with the seeker, guidance electronics, autopilot, or control system independently to characterize and evaluate these elements. HWIL simulation can vary from only one missile hardware element in the loop (such as the seeker, guidance electronics, autopilot, or control system) to multiple missile elements plus actual jammers and elements of the ground radar. Open- and closed-loop simulations can be simple or complex depending on the fidelity required for the modeled element or phenomenon. The primary applications of the RFSS are static or dynamic open-loop simulation of missile flight hardware or verification of software models and closed-loop simulations in which the missile guidance hardware is tested dynamically with all other elements of the system.

1. Open-Loop Simulation

Open-loop simulation is used primarily to define or verify seeker characteristics such as tracker response, automatic gain control (AGC) characteristics, variable frequency oscillator (VFO) frequency, boresight errors, and noise levels. Open-loop testing is also used to determine the seeker response to various ECM techniques and to distributed sources such as clutter and multipath. Autopilot and elevon actuator performance can also be evaluated economically in an open-loop configuration. Hardware open-loop simulations provide performance data for hardware evaluation or information for the development of software models. The overall simulation capability and efficiency is enhanced by the availability of both verified hardware and proven software models.

2. Closed-Loop Simulations

The dynamic closed-loop guidance simulation may be an all-software (analytic) simulation or may incorporate one or more of the flight hardware items shown in Figure 3. Hardware elements of a ground radar may also be involved. Flight hardware within the total closed-loop may be exercised as individual units or in some combination such as an elevon system with the autopilot or autopilot with the guidance sensor.

As depicted in Figure 3, closed-loop guidance simulations can be conducted in the RFSS for all types of radar guidance systems: passive, semiactive, active, command, beam rider, and TVM. Active and passive systems involve signal propagation between missile and target. Three signal paths are involved in semiactive and TVM systems.

For either open-loop evaluation of flight hardware or closed-loop guidance simulation with HWIL, the RF environment for the flight hardware is physically simulated in the RFSS. The three categories of the simulated environment are identified in Figure 4 by the three boxes with the widened lower edge: aerodynamic moments, angular motions, and the electromagnetic environment.

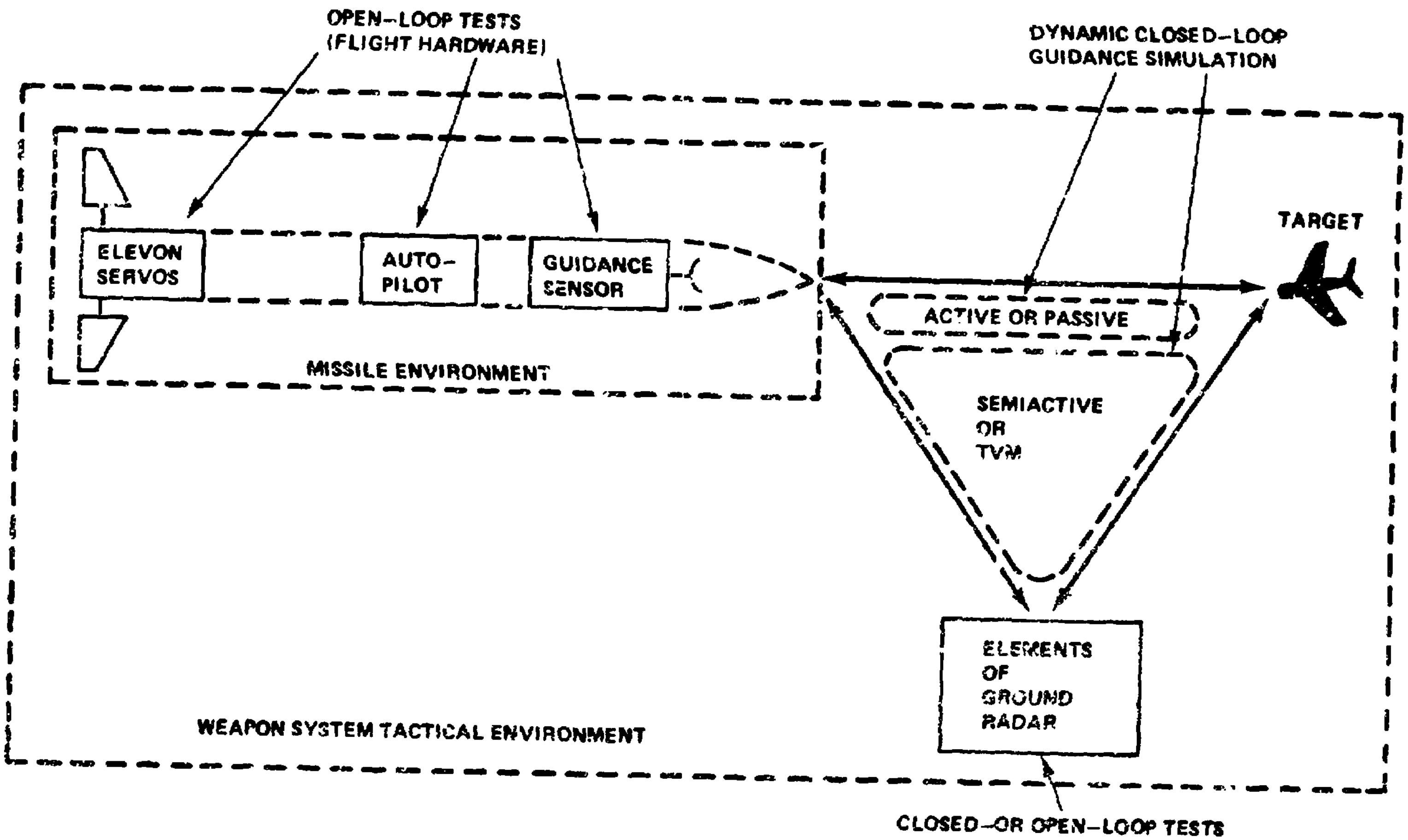


Figure 3. RFSS primary applications.

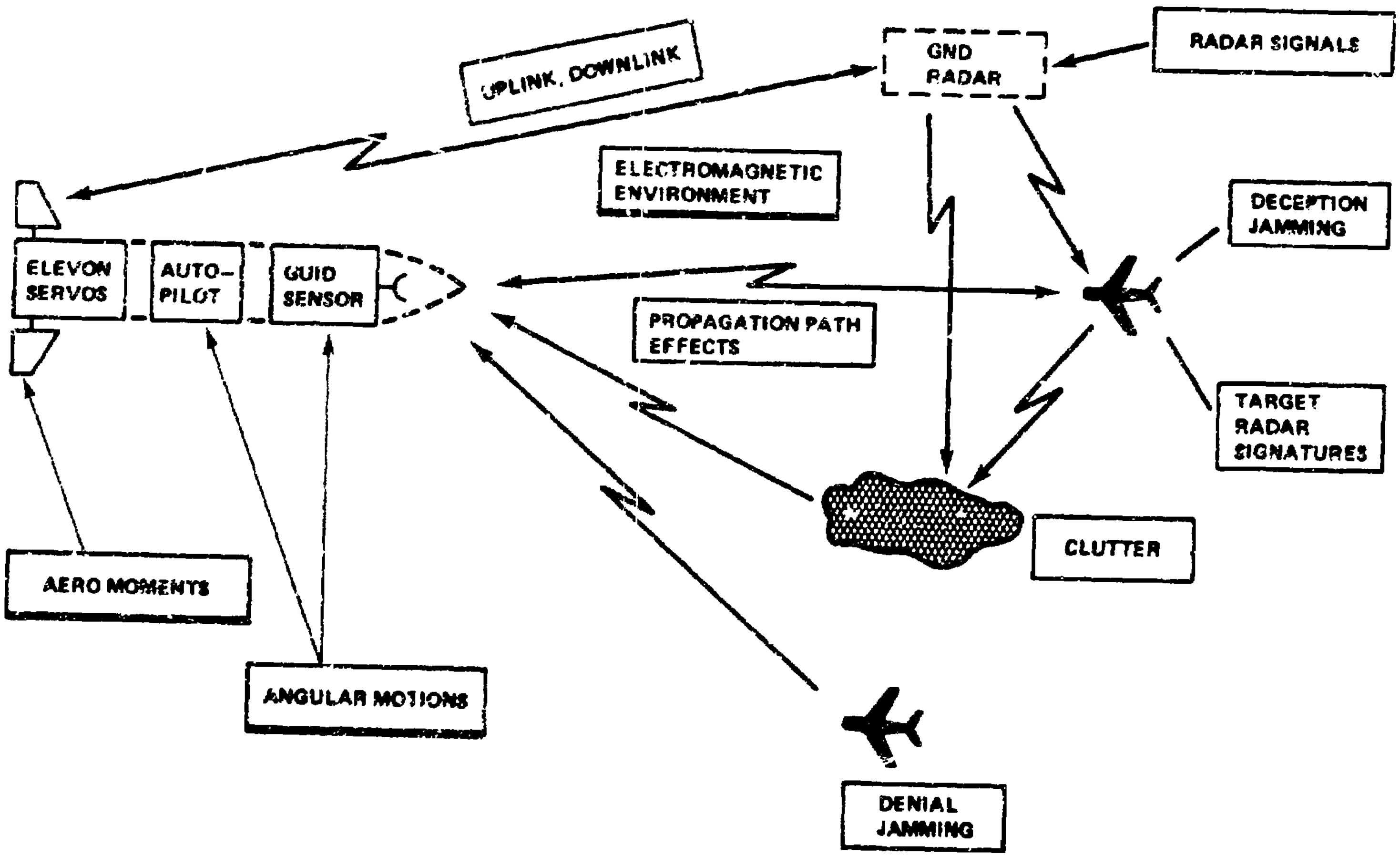


Figure 4. Flight hardware environment.

The electromagnetic environment is illustrated in Figure 4. For example, propagation path effects include range delay, space loss, line-of-sight rotation, and other atmospheric anomalies. Target radar signatures include glint, scintillation, and Doppler effects.

Figure 5 identifies the RFSS equipment which is used to simulate the environment for the flight hardware and the type of software required to represent other elements of a missile/target engagement. As shown in the hardware section of Figure 5, a Control System Aerodynamic Loader (CSAL) simulates aerodynamic moments on elevon shafts, and two three-axis rotational flight simulators (TARFS 1 and 2) simulate missile rotational motions for the guidance sensor and autopilot gyros, each mounted separately on individual tables. The electromagnetic environment for the guidance sensor is simulated within a shielded anechoic chamber by means of an RF signal generation system which feeds RF signals to the target and ECM arrays.

The chamber provides a free-space environment for the radiation of signals from the target and ECM arrays to the guidance sensor. Up to four simultaneous, independent target signals with continuously controllable polarization parameters can be radiated from the target array in the 4- to 12-GHz spectrum and up to two independent target signals in the 12- to 18-GHz frequency range. In the 2- to 4-GHz spectrum, four targets can be generated and displayed by the addition of power amplifiers in the RF generation subsystem. One or two simultaneous denial ECM signals can be radiated from the ECM array. Denial ECM signals can be either vertically, horizontally, or circularly polarized. Two-dimensional motion of the phase-center of radiation of the target array simulates pitch (Y) and yaw (X) target motion. Downrange (Z) motion of the target is provided by RF amplitude control.

The RF Signal Generation System initiates signals with the time, frequency, phase, and amplitude characteristics required to simulate radar reflections from airborne targets, denial and deception jamming techniques, and distributed sources. By means of coaxial-cable and waveguide paths between the RF Signal Generation System and the guidance sensor, simulated reference or uplink signals, and fuzing signals may be inserted at appropriate points in the guidance sensor. The hardwired paths also provide a route for downlink signals.

The software section of Figure 5 depicts in a general manner the software that represents other elements of a missile/target engagement. Block 1 contains the missile mass, motor, and aerodynamic models. The outputs of Block 1 are missile aerodynamic force and moment coefficients, mass, center-of-mass location, moments of inertia, motor thrusts, etc.

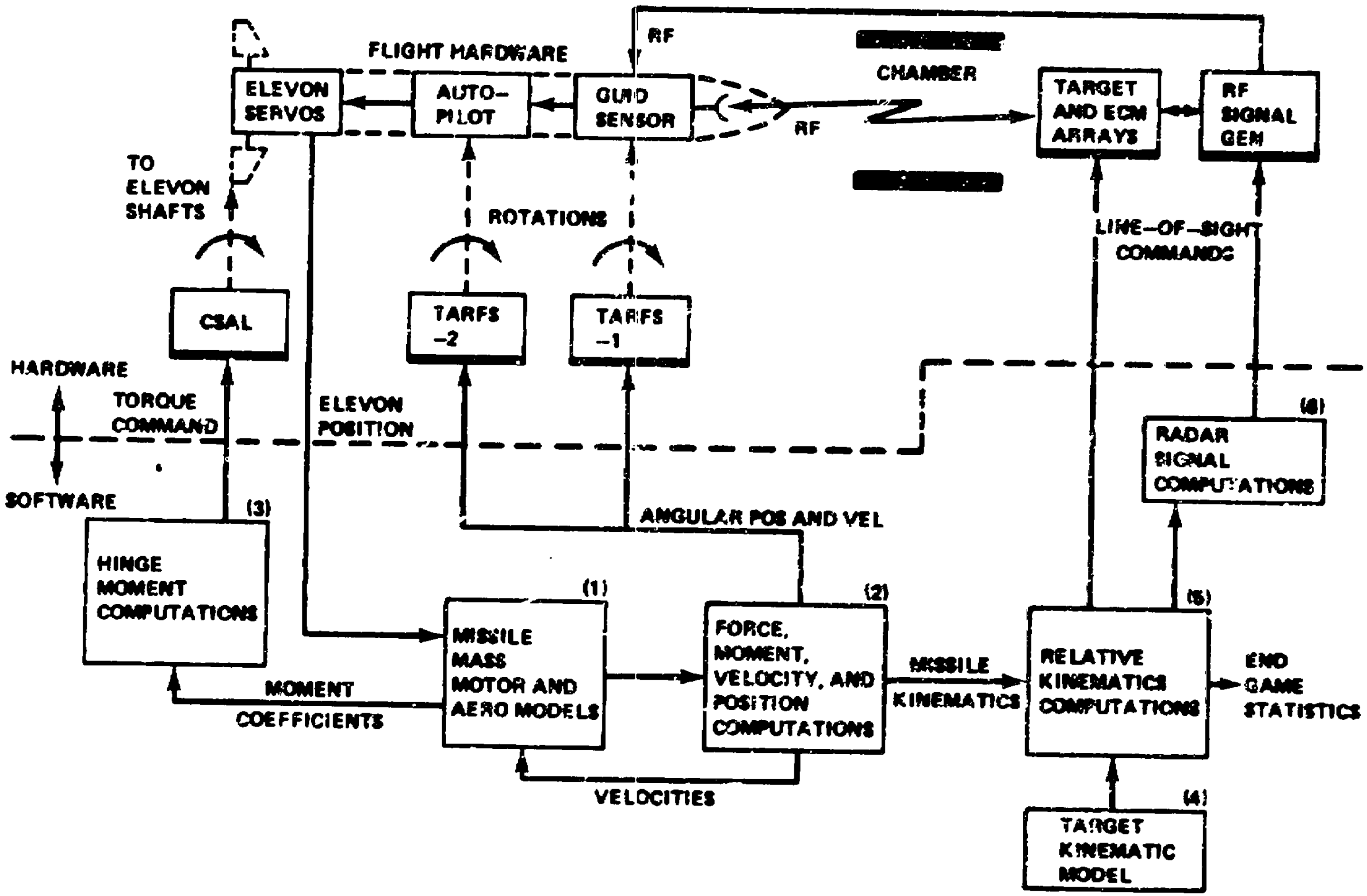


Figure 5. ASC missile environment and closed-loop guidance simulation.

In Block 2 of Figure 5, missile linear and angular accelerations are computed; these quantities are integrated to determine missile linear and angular velocities and positions. These computations are performed in the missile coordinate system; therefore, a missile-to-facility coordinate transformation is required to determine position and angular rate commands for the TARFS.

From Block 2, missile velocities are fed back to Block 1 where elevon aerodynamic-moments coefficients are computed. Hinge moments are computed in Block 3 to derive torque commands for the CSAL. The positions of the elevons are fed back from the elevon servos to Block 1.

Missile kinematics from Block 2 and target kinematics from Block 4 are used to determine missile/target relative kinematics in Block 5. From repetitive runs of the guidance simulation, end-game statistics are determined. End-game statistics include miss distance, miss angle, missile angles-of-attack, closing speeds, relative orientation of missile and target, etc. End-game statistics are used in fuzing-, warhead-, and kill-effectiveness studies.

B. RFSS Physical Characteristics

The rooms and equipment in the RFSS facility are identified in the cut-away and plan views, Figures 6 through 9. In the following paragraphs, the rooms and equipment within each room are briefly described.

1. ECM Room

The ECM room is reserved for incorporation of special-purpose ECM equipment into the simulation. The ECM equipment may be used in conjunction with open- or closed-loop guidance simulations or guidance-sensor tests. Signals from the ECM room may be routed by coaxial cable or waveguide to the target (main) array, the ECM array, or the electronic subsystems of a missile system being exercised in the facility.

2. Lower RF Room

The lower RF room contains low-power RF generation modulation equipment, and the interface equipment between the master computer located in the control room and the target array and RF generation equipment. A keyboard printer is also used in conjunction with the interface equipment which contains six minicomputers.

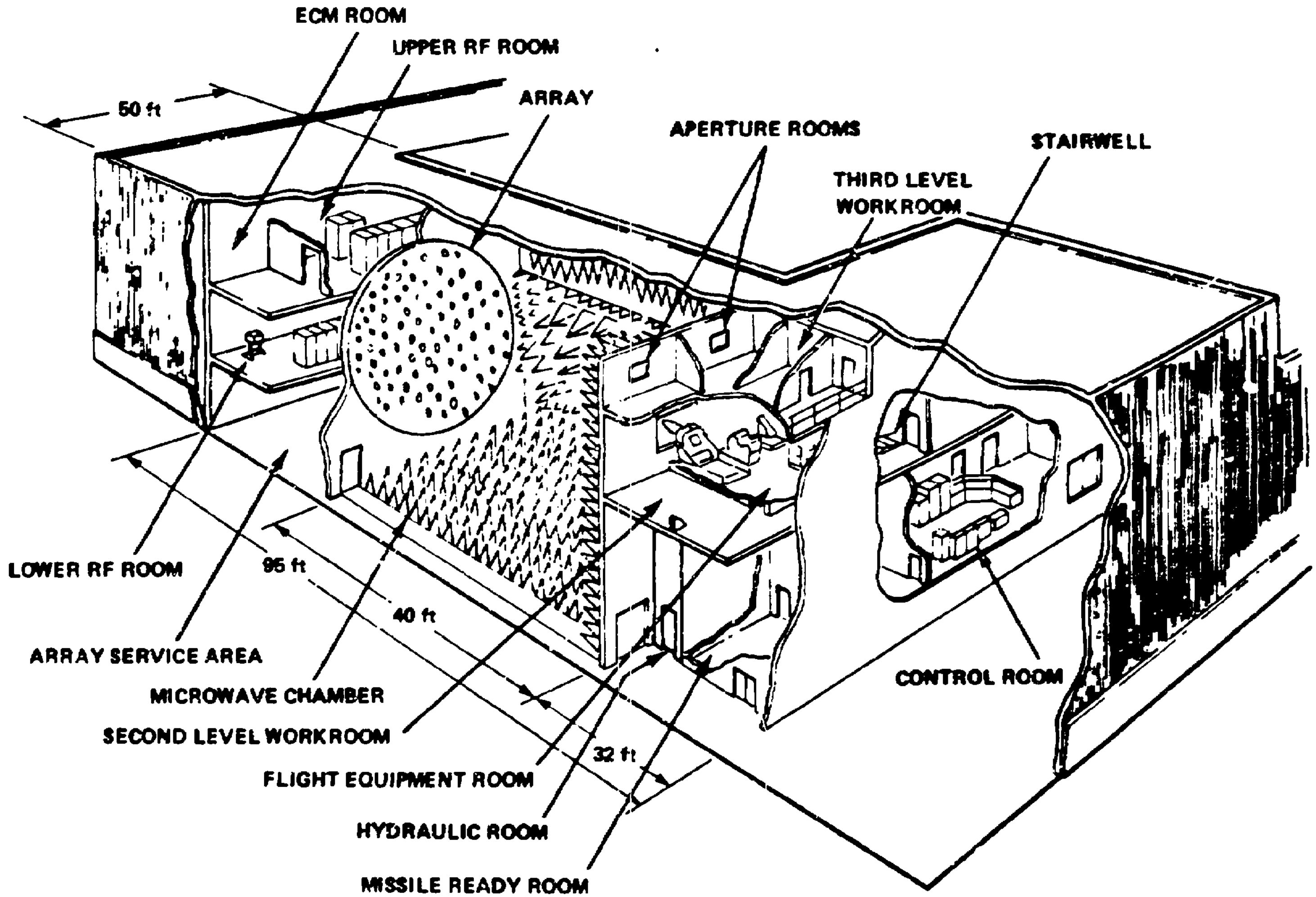


Figure 6. RFSS facility.

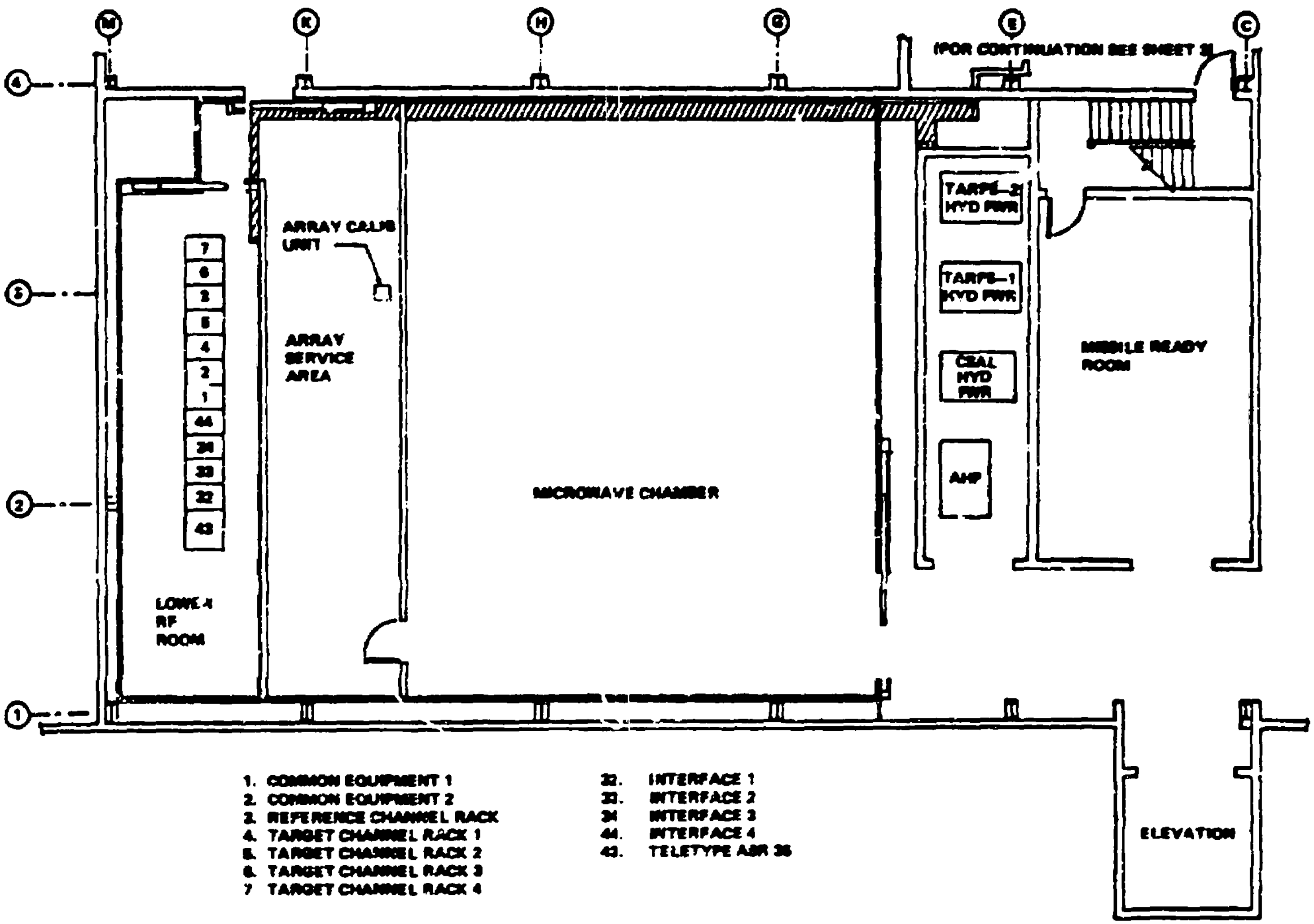


Figure 7. Plan view, first level.

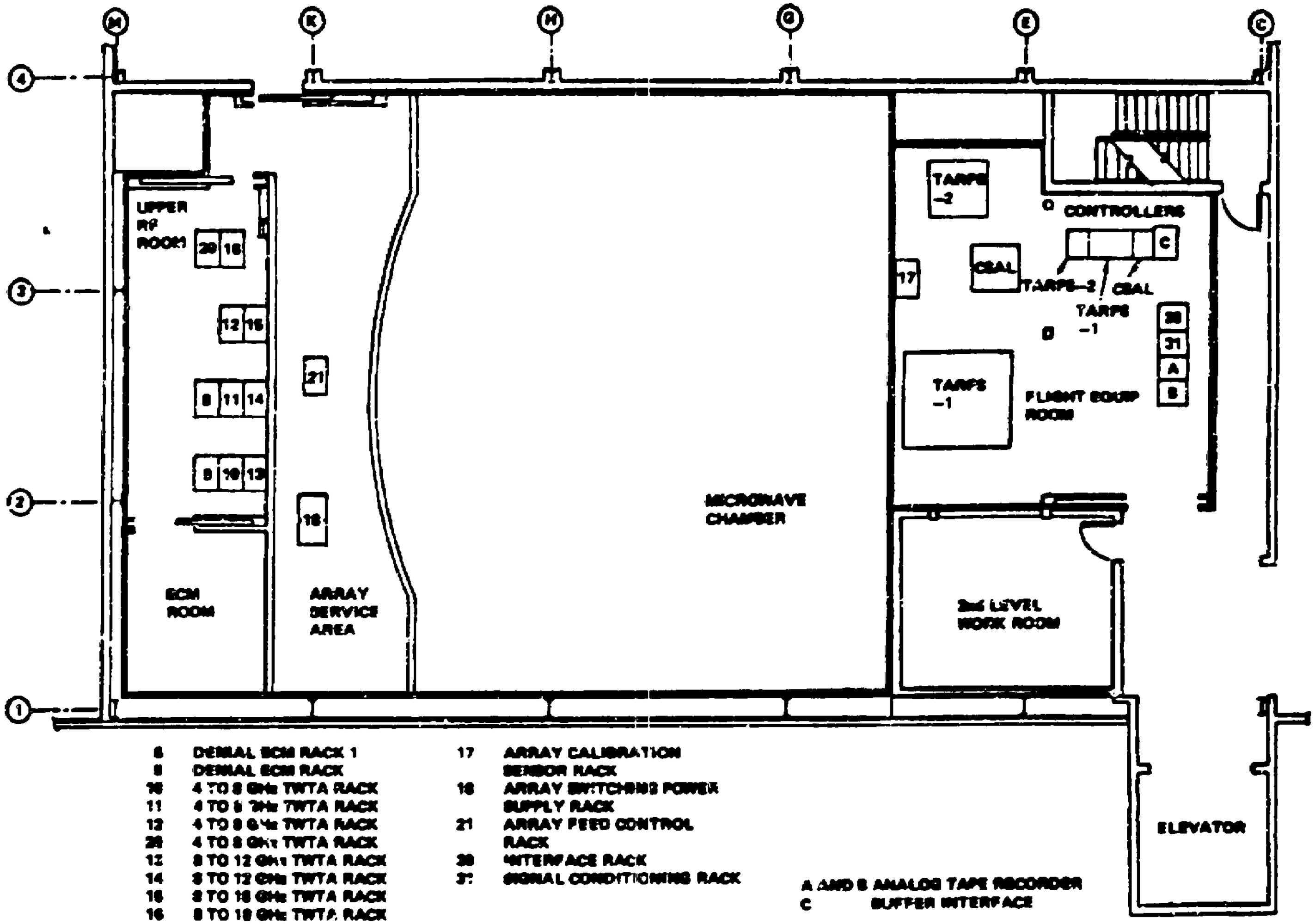
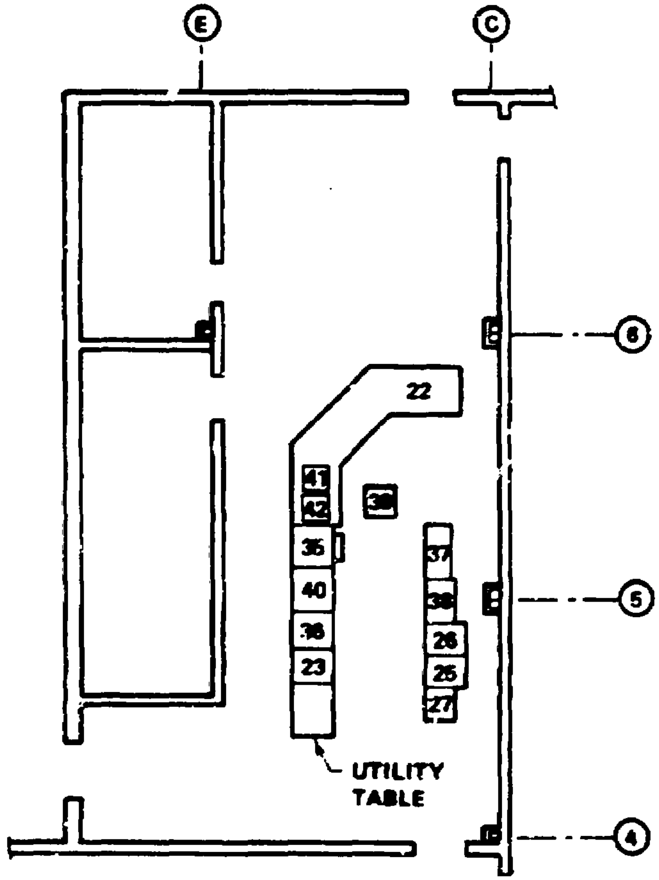


Figure 8. Plan view, second level.



22. CONTROL CONSOLE
23. INTERFACE EQUIPMENT RACK
25. BRUSH RECORDER
26. BRUSH RECORDER
27. VARIAN RECORDER
35. CONTROL COMPUTER (MAIN FRAME)
36. CONTROL COMPUTER (DISC STORAGE RACK)
37. CARD READER
38. LINE PRINTER
39. TELETYPE ASR33
40. CONTROL COMPUTER (MEMORY EXPANSION RACK)
41. 4012 DISPLAY TERMINAL
42. 4610 DISPLAY HARD COPY

Figure 9. RFSS control room.

Low-power RF signals are used as inputs to high-power RF generation equipment located in the upper RF room, and guidance and fuze electronics of a guidance sensors mounted on TARFS-1. Five independent low-power RF signal channels, four target channels, and a reference are available in either C or X bands; two independent low-power RF signal channels are available at Ku-Band at this time.

3. Upper RF Room

The upper RF room contains the high-power C-, X-, and Ku-band amplification equipment, and the DENIAL ECM generation equipment. Four independent high-power amplification channels are available in C-band. Another two amplification channels cover X-band. Each of two additional channels cover either X or Ku-band. Each of the two DENIAL ECM generators covers the bands 4 to 8 and 8 to 12 GHz. The high-power channels are usually routed to the four channels of the target array; however, they may be routed through either of the two ECM array channels for some unique simulation test requirements. The DENIAL ECM signals may be routed to the ECM array, any channel of the target array, or subsystems of a missile system being tested in the laboratory.

4. Array Service Area

The array service area contains the target array and ECM array feed system components and control electronics, antenna mounting fixtures which enable array antennas to be positioned in six degrees-of-freedom, and work platforms for service work behind the array.

5. Microwave Chamber

The shielded anechoic chamber (48- × 48-ft high/wide × 40-ft long) provides a free-space environment. The target and ECM antenna arrays are located on the south wall of the chamber. One primary aperture and two secondary apertures are located on the north wall. The primary aperture is centered on the logitudinal axis of the chamber. TARFS-1 is located in the primary aperture. The two secondary apertures are located above the primary aperture and provide additional space for open-loop sensor evaluations.

The target array consists of 534 antennas located at a fixed radial distance from the intersection of the TARFS-1 gimbal axes. The conical field-of-view provided by the target array is approximately 42°. The target array can transmit a maximum of four simultaneous independent signals and can also receive signals from an active guidance sensor.

On the target array, the apparent location (phase center) or radiation of a target is controlled by selecting a triad of adjacent antennas which are to radiate and controlling the relative amplitude and phase of the three radiated signals. The amplitudes and phases of the signals determine the phase-center location within the triad. The target array is not a phased array but a matrix array in that target positions are controlled through phase center motion.

The polarization of signals transmitted from the target array is controllable. Each of the target array antennas consists of two orthogonal linearly polarized elements. Rotatable linear, left- and right-hand circular, or variations of elliptical polarizations are obtainable by the control of the relative amplitude and phase of the signals radiated by the two orthogonal elements of each antenna. Polarization and phase-center location are independently controllable through attenuators and phase shifters located in the array feed control rack.

The ECM Array consists of 16 antennas distributed among the target array antennas. Each of two independent ECM signals can be radiated from one of the 16 ECM antennas or the two signals may be applied to different antennas. The radiated signal may be horizontally, vertically, or circularly polarized.

6. Aperture Rooms

The aperture rooms provide significant capability for general seeker characterization evaluation and related tests when closed-loop operation is not required. The aperture rooms provide the capability for integrating the seeker with associated mechanical, electrical, and electronic interfaces and the facility; conducting certain open-loop testing against radiating source(s); determining seeker operational characteristics; and establishing required scaling, recording, and data flow parameters. The aperture rooms can be utilized for static RF tests or for integration and check-out prior to closed-loop simulation in the flight equipment room. Typical aperture room configuration and interface with the RFSS facility are shown in Figure 10.

7. Flight Equipment Room (FER)

The FER contains hydromechanical equipment (the two TARFS and the CSAL) and electronic interfaces. The interface equipment connects or enables connections to be made among the flight equipment; the TARFS-1, -2 and CSAL control electronics; the master computer; the US Army Missile Research and Development Command (MIRADCOM) Hybrid computer complex; RFSS recording equipment; and the RFSS and the other ASC cells [the electrooptical simulation system (EOSS) and the infrared simulation system (IRSS)].

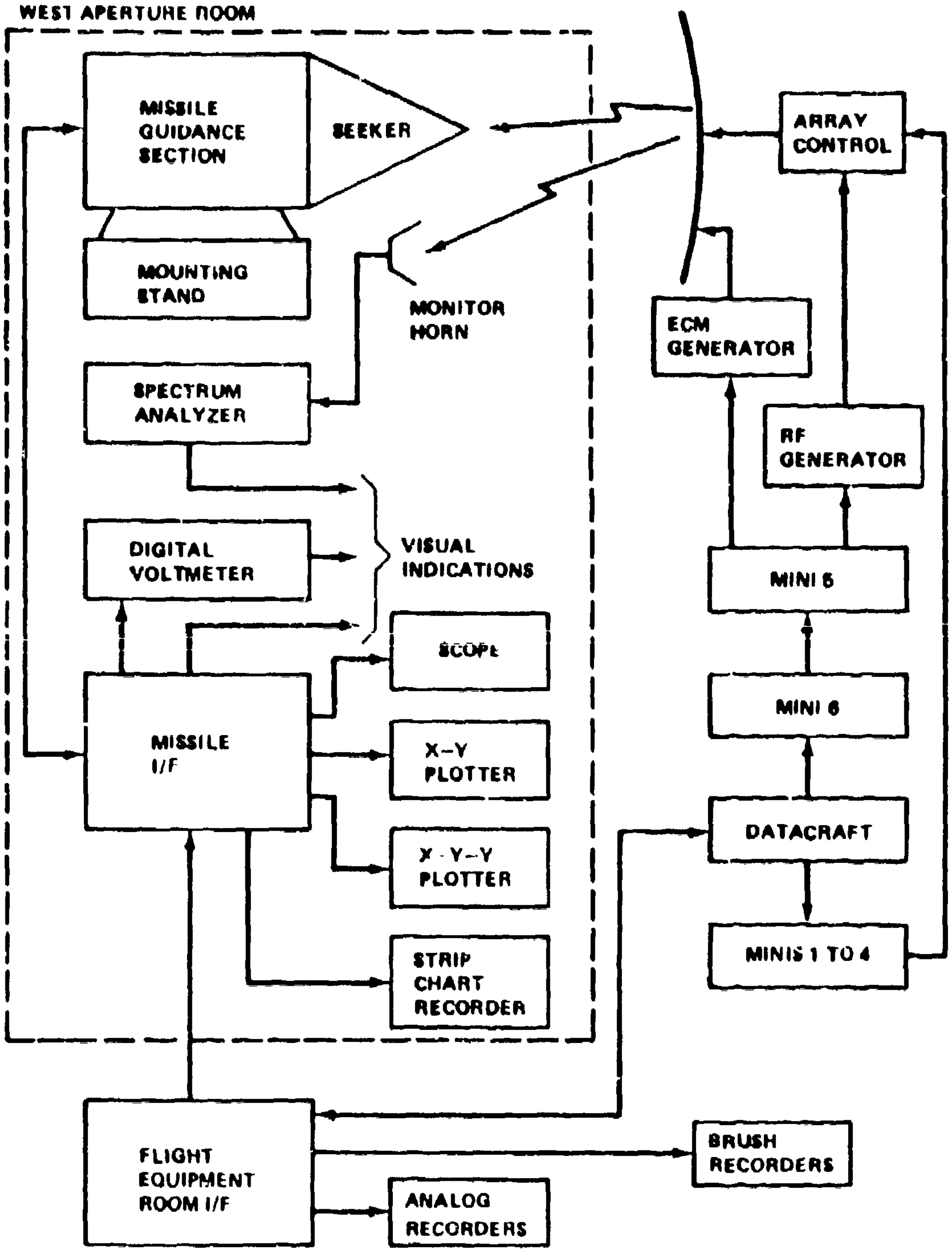


Figure 10. Typical configuration and interface for the aperture room.

8. Hydraulic Room

The hydraulic room contains four hydraulic power supplies. Three power supplies serve the TARES-1, -2, and CSAL. An auxiliary hydraulic power system (AHPS) provides power for missile flight hardware being exercised in the FER.

9. Control Room

The control room contains the master computer, computer peripherals, the RFSS control, recording and display equipment, and the test conductor's console. The master computer has two spare I/O channels to enable connections with the ASC hybrid computer complex.

C. Simulation Examples (Closed-Loop)

Functional diagrams of passive, semiactive, and active missile simulations are shown in Figures 11, 12, and 13. Actual missile hardware is used for the seeker antenna, gimbals, and electronics. Special interfaces are fabricated to mate (mechanically, hydraulically, and electronically) the missile hardware to the RFSS facility.

The simulation is started by the test conductor at the Weapon System and Simulation control panels. The master computer generates both the target and missile initial trajectories in space coordinates. The master computer then converts these space coordinates to RFSS coordinates and feeds the target- and reference-signal commands to the master/mini interface and the missile commands to the FER interface. Software models of the mass, motor, and aerodynamics of the missile are implemented in the ASC hybrid computers and enable the guidance loop to be closed via the direct cell interface with the RFSS facility. The targets are energized and the missile seeker is enabled in a launch sequence identical to the real world situation.

The target-control and reference-signal commands pass through the master/mini interface to six minicomputers. Minis 1 through 4 control the angular positions of four targets on the array. Mini 6 generates the target glint and scintillation update commands based upon resident software target models and current target-missile trajectory information; it then outputs these commands to the other five minis for implementation in their programs. Mini 5 adds scintillation and Doppler to the simulated target and develops RF generation hardware amplitude- and frequency-control signals.

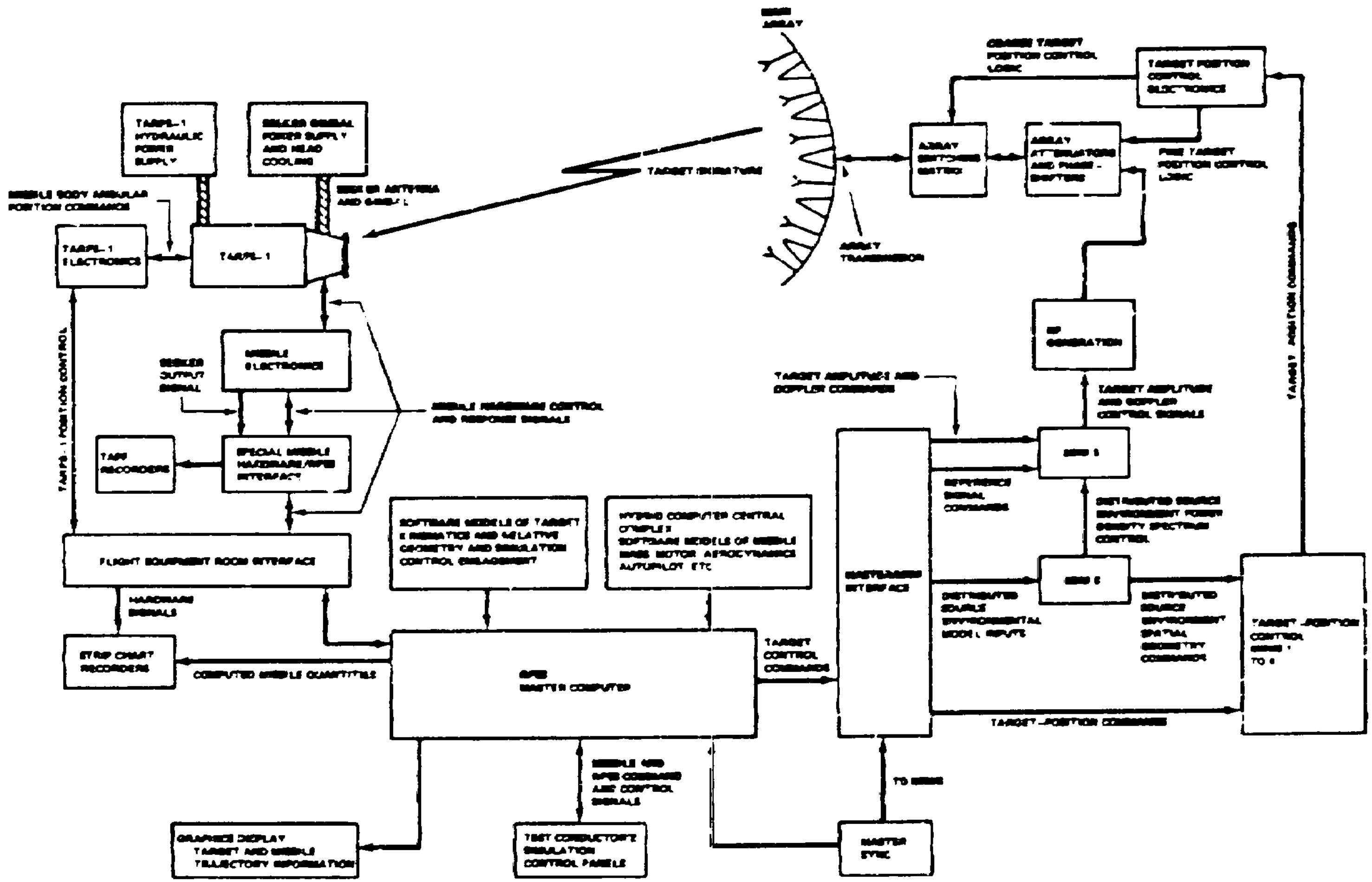


Figure 11. Passive missile simulation.

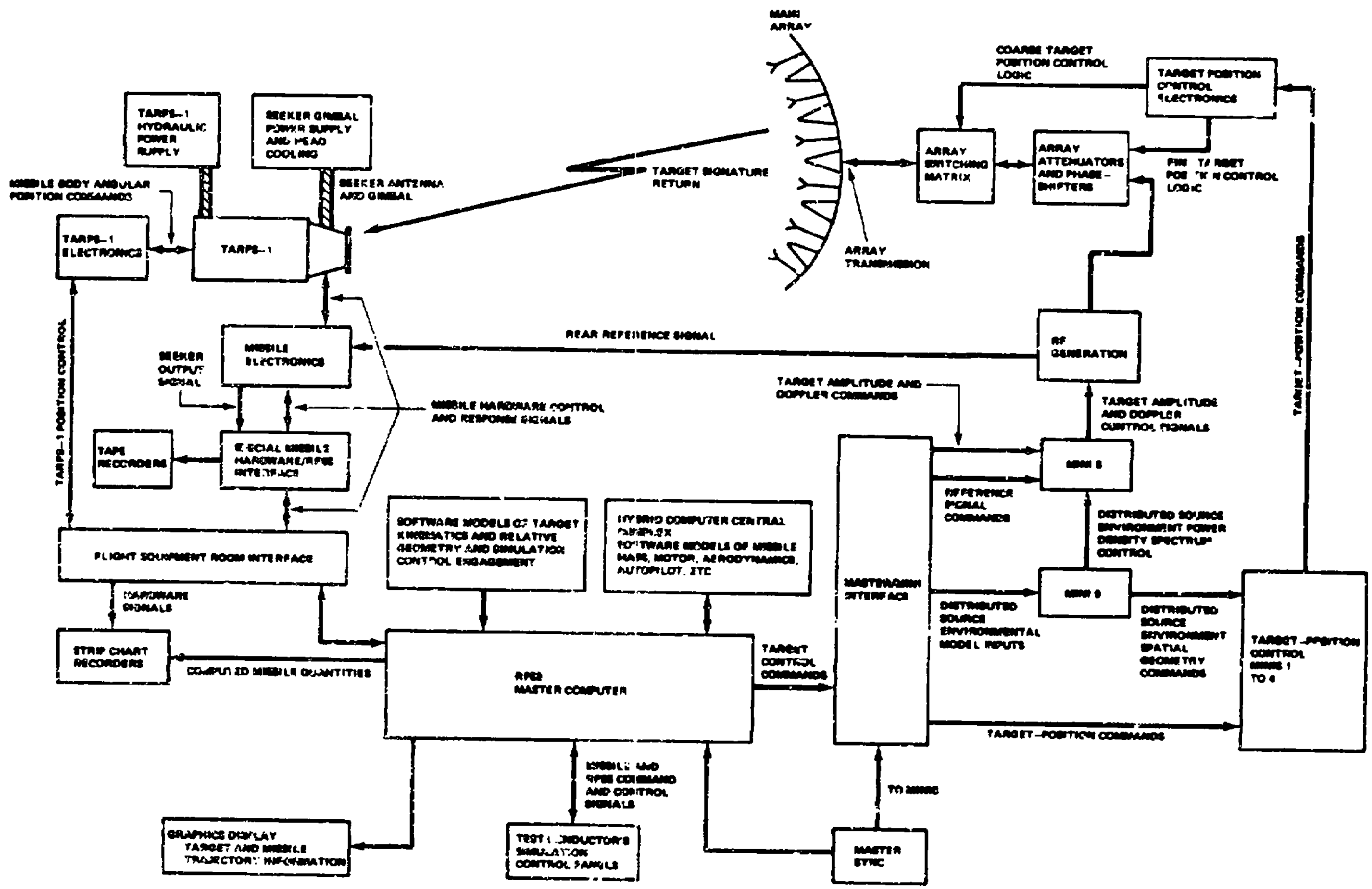


Figure 12. Semiactive missile simulation.

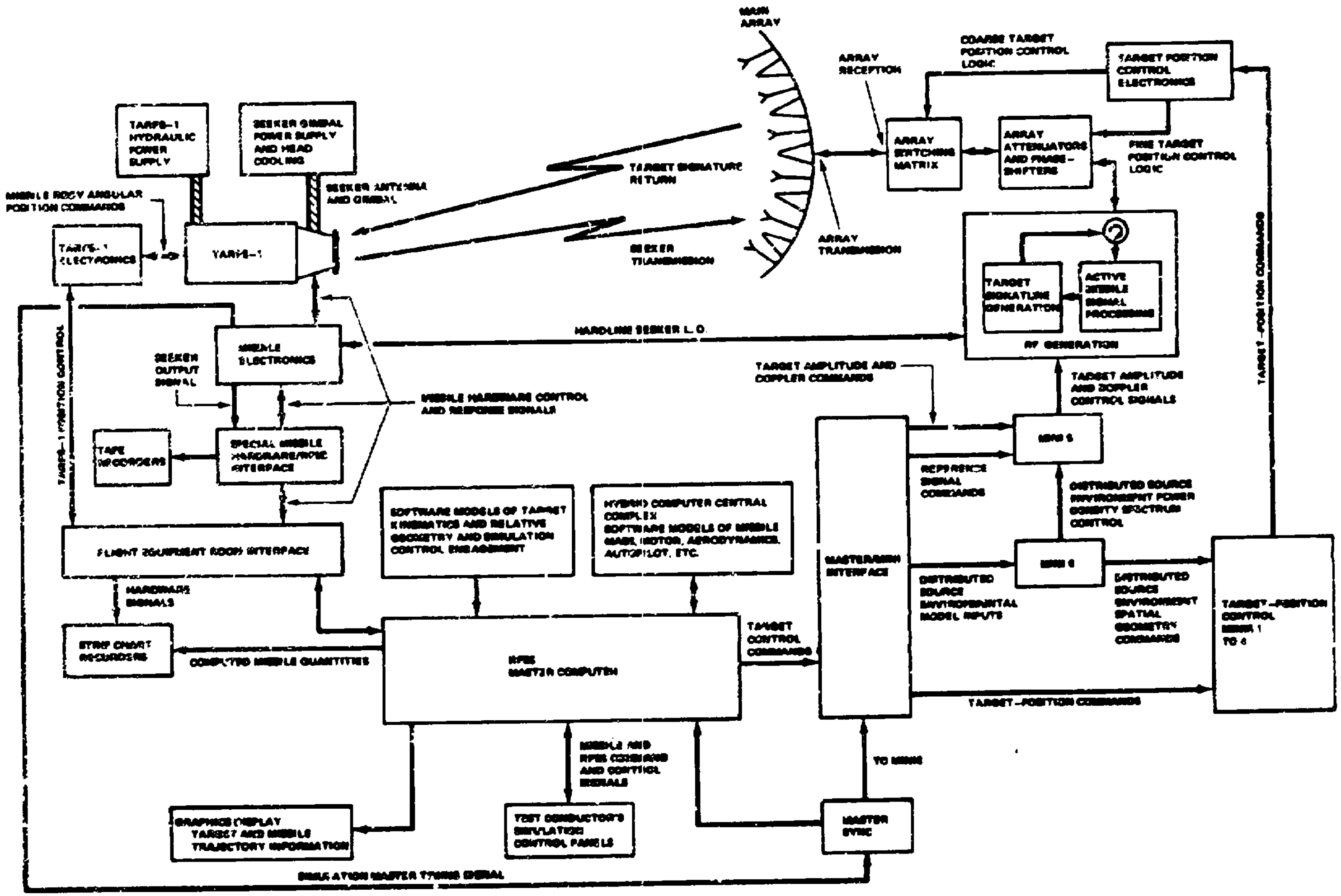


Figure 13. Active missile simulation.

The RF generation subsystem produces both the target-reflected and reference signals. The target signal is coupled to the main array and radiated toward the seeker from controlled angular positions. The reference signal is transmitted to the missile electronics via coaxial cable or waveguide. The reference signal simulates the signal received by the missile directly from the illuminator.

The missile seeker receives the target signals from the main array and generates homing guidance signals. These guidance signals are coupled through the special missile interface and FER interface into the master computer. The master computer then generates new target and missile commands and updates both commands.

Meanwhile, the missile commands from the master computer have gone through the FER interface to the TARFS-1. These signals drive the TARFS-1 hydraulic gimbals to simulate the missile-body angular motions that occur in actual flight. The proper angular position and rate environment are therefore generated by the gimbals of the seeker.

The simulation is a closed-loop guidance simulation operating in real time with actual missile HWIL. The simulation starts at missile activation and ends when the missile is at the point-of-closest-approach to the target. The simulation timing is synchronized by a master sync and runs at the speed set by the sync. For simulations which involve detailed missile models, the ASC hybrid computer complex is employed through the direct cell interface with the RFSS interface. The interface allows for the flight aerodynamics, the autopilot, and the missile control surfaces to be modeled using only analog computers, hybrid computers, or a digital computer (CDC 6600).

Information recorded on the strip-chart recorders and on digital and analog magnetic tape includes the same data that are normally telemetered to the ground in actual missile flight so the ASC data can be compared directly with the actual flight test data. In this manner, the simulation constants can be varied to "match" desired flight test conditions. In addition to the normal telemetered data, recordings are made of various other missile/target flight parameters as required to assess simulation and engagement performance.

Up to four simultaneous independently controllable targets can be simulated; each has unique and independent radar signatures which vary with target roll and aspect angle. The simulated targets may represent helicopters, aircraft, missiles, or surface RF emitters. Target angular and radial motions are limited by the 3-msec update rate of the array and the amount of motion between updates that is acceptable to the user. Target angular position accuracy is nominally 1 mrad with the ability to provide more accurate angular position if required. Target radial position accuracy is Range ±6% with the ability to command range in 0.6% increments. The 3-msec update rate and the accuracies stated

previously have provided more than adequate target position and motion capability for realistic engagement scenarios using the HAWK, Standard Antiradition Missile (ARM), and similar missiles versus aircraft such as the A-4 and F-4.

D. RFSS Planned Modifications and Expansion

Plans for RFSS capability expansion through 1979 are as follows:

Capability	Availability
Improvement of analog tape recording system	1977
Augmented RF interface to provide RF and target control from the lower RF room, the FER, and the aperture rooms.	1977
Additional cabling between RFSS rooms to facilitate data transfer	1977
Addition of radome boresight positioner.	1977
Target array real-time display.	1977
Two additional targets, two ECM channels, and one reference channel in the 12- to 18-GHz range.	1978
TARFS-1 modified to provide continuous roll with increased angular velocities and acceleration rates.	1978
Universal weapon system interface (to minimize interface requirements for individual programs).	1978
Second Datacraft, increased disc capacity, increased minicomputer memory, and digital magnetic tape recorder.	1978
Addition of a seventh minicomputer with its own teletype for software and minicomputer hardware checkout.	1978
Redesign of the master/mini interface to divide the interface into two drawers with interface to three minis through each drawer.	1978
Static three-axis seeker positioners for aperture rooms.	1978
Four targets in the 2.0- to 4.0-GHz range.	1979
Improved RF distributed source modeling.	1979

E. ASC Multimode Simulation Capability

The ASC has the capability of multimode seeker simulation, i.e., simulation of missile systems that use RF, electrooptical, or infrared sensors in some combination for the different phases of the missile guidance during flight. The simulation is accomplished by integrating the three ASC Cells (RFSS, EOSS, and the IRSS) via the hybrid computing complex in the proper sequence to simulate the various missile guidance phases.

II. ENVIRONMENTAL MODELING

A. General

A useful electromagnetic simulation of the real world required that the electromagnetic environment be modeled faithfully. The various target signatures, ECM, clutter, multipath, rain, and chaff must all be modeled. The degree to which the electromagnetic components are modeled depends primarily on the engagement scenario. For example, in simulations such as an ECM scenario where the change in target and CM signature with respect to aspect angle is critical to determining the jammer-to-signal (J/S) ratio, extensive look-up tables are required because both the target signature and the CM emission change as a function of aspect angle. For other engagements where target signature variations are not as critical, standard Swerling target models or even elementary target models might be adequate. Continuous improvement in the ability of the RFSS to provide a high-fidelity electromagnetic environment is a priority endeavor.

B. Target Signatures and ECM

Swerling target modeling is accomplished on Mini 6, where the algorithm determining angular glint is used as an input to the four target minis to determine the target's position on the array; the scintillation algorithm output is used to vary the RF generation range attenuator output. The more complex, look-up table target models are implemented in tables on the RFSS master computer. The engagement geometry is used to determine the target aspect angle. From this, the proper look-up table value is determined; this information is used as a control parameter for the range attenuators. Glint and scintillation may be added to the baseline table value via either algorithms in Mini 6 or other look-up tables on the Datacraft.

The RFSS ECM capability is extremely diverse. Either denial or deceptive jamming techniques can be simulated with present equipment. Two denial ECM channels are available and can be used either to simulate a standoff jammer whose relative motion in an engagement is slight, but whose power capabilities are high, by being fed to one of the 16 antennas on the ECM array or to simulate a broadband on-board noise jammer in a self-screening jammer mode. Approximately 20 dB more power is obtained when a signal passes through the ECM array versus the main array. The power differential is due to the simplification of the ECM array feed structure. This difference can be interpreted as a maximum end-game J/S ratio of 20 dB. The denial ECM channels have both continuous wave (CW) and pulse capabilities. Specifications for the two denial channels are summarized in Table 1.

Deceptive jamming techniques can be accomplished by proper modulation of any target channel. Present RF generation capability includes Gaussian and binary noise, linear frequency modulation (FM), square wave, swept square wave, sawtooth, and several others. Some of these techniques include use of analog equipment to modulate the channel directly while others are implemented by digitally synthesizing the signal on Mini 6 and using digital-to-analog (D/A) channels to convert the signal for input to analog jacks in the equipment rack. Up to two targets, each with an onboard jammer, can be simulated. In certain simulations, it may be feasible or desirable to use fielded or experimental jammers as part of the RF equipment. This configuration is easily accommodated by using the jammer as part of one of the target channels. The jammer is integrated into the RF system with the proper interface and becomes an integral contributor to the simulation of the RF environment. One target channel is used to simulate the particular target signature and the target channel with the jammer is colocated on the main array to generate the on-board jamming signal. In a escort screening scenario, one jammer and two targets can be simulated.

C. Clutter, Multipath, and Chaff

Advanced distributed source modeling concepts and techniques are being studied for HWIL simulation. This study, scheduled for completion in December 1977, is considering both hardline injection into the test specimen and radiation techniques on the main array. The primary conclusions of the study will define advanced methods for distributed source generation and the necessary hardware and software for implementation (scheduled for availability in 1979). The study will also define the environmental spectrums that can be radiated from the main array with existing equipment.

TABLE 1. CONTROL RANGE, RESOLUTION, AND UPDATE RATE OF RF SIGNAL PARAMETERS

Signal Parameter	Unit(s)	Control Range	Resolution	Update Rate	Notes
Doppler Shift	IF Frequency Synthesizer	MSW @ 140 MHz + 15 MHz ± 15 MHz	0.3 Hz	5 msec	
Range (Time) Delay	Time Delay Generators	0 - 9.999999 msec	1 nsec	1 msec	This is relative (target-to-target) delay.
Linear FM Chirp	Chirp (LFM) Generator	$20 \le T.B. \le 450$ Up/Down Chirp	1 μsec $\le T \le$ 150 μsec 2 MHz $\le B \le$ 35 MHz	Master Computer Command	
Center Frequency	Diversity Programmer	4 to 12 GHz 4 Targets, Ref. 12 to 18 GHz 2 Targets	1 MHz	Pulse-to-Pulse in Diversity Mode upon Master Computer Command Otherwise	Full range not under computer control without manual selection of filters.
Power Level (Including Scintillation)	High and Low Level Attenuators Ref. Attenuator Fuze Attenuator ECM Attenuator	Target Channels: 0 to 130 dB Ref. Channel: 0 to 120 dB Fuze Channel: 0 to 60 dB ECM Channels: 0 to 60 dB 60 to 100 dB	0.5 dB 0.5 dB 1 dB 1 dB 40 dB	1 msec 5 msec 1 msec Master Computer Command Master Computer Command	
Pulse Repetition Frequency (PRF)	Low PRF Generator High PRF Generator	1 Hz to 100 KHz 100 Hz to 1.0 MHz	Resolution of period = 10 μsec Resolution of period = 0.1 μsec	5 msec	Max Duty Cycle 5% Pulse - 5 μsec PW Limit
Pulse Code	Pulse Code Shift Register	0 to 256 bits 0 to = 1024, Functions of Low PRF		Master Computer Command	
Pulse Shape	Pulse Shaper	Rise and Fall Time: 10 nsec to 100 μsec Width: 15 nsec to 40 msec PW 5 μsec Max for 1-kW Operation	0.1 nsec min 0.1 nsec min	Master Computer Command	Resolution is a function of the setting.
Denial ECM Center Frequency	ECM Center Frequency	4 to 12 GHz	2 MHz	10 msec	Master Computer Command
Denial ECM AM	ECM AM	0.5 to 150 MHz BW	Internal: 0.5,1,5,10,20,150 MHz External: External Source Limit	Manual	
Denial ECM FM	ECM FM	Center Frequency Deviation ±800 MHz, 4 to 8 GHz ±1.6 GHz, 8 to 12 GHz Rate Sawtooth 1 kHz to 10 MHz Sine 50 kHz to 50 MHz Noise 0.5 to 50 MHz BW External 0 to 50 MHz	800 kHz 1.6 MHz 50 Hz Smoothly Variable 0.5,1,5,10,20,50 MHz External Source Limit	Master Computer Command Master Computer Command Master Computer Command Manual Manual Manual	
Noise Gen.	Gain and Binary	0.00015 Hz to 50 kHz	Step (DEC)	Manual	3 sect

Present RFSS capability allows for basic simulation of single- and two-tone clutter. Techniques are being developed to radiate a complex clutter signal adequately from the target array. Three channels are required: one to radiate the sum pattern on-axis and two others to radiate the azimuth and elevation difference patterns off-axis. It is possible, however, that sufficient clutter spectrum fidelity can be obtained by radiating only two signals: the elevation difference pattern and the sum channel pattern. The sum channel pattern is radiated slightly off-axis in azimuth such that some clutter signal is coupled into the difference aximuth channel. Results with this method should not differ significantly from the three-channel clutter approach due to similarity in spectral characteristics between the difference azimuth channel and the sum channel.

The simulation of multipath, both specular and diffuse, will be implemented in much the same way as the clutter simulation, with two significant differences:

1) The angle of the multipath signal is different.

2) The power density spectrum is much narrower.

Although a true chaff simulation cannot be accomplished, it is possible to simulate the effect of chaff on specimen performance by using the same basic clutter model and modifying it to yield chaff spectral characteristics.

III. TARGET GENERATION

The control range, resolution, and update rate of the RF signal parameters are summarized in Table 1. The array hardware performance parameters are presented in Table 2. The target generation and array capability is summarized in Table 3. The effective radiated power (ERP) of the array is summarized for representative frequencies and modulations in Table 4.

The antenna array is located on the concave (front) surface of a spherical metal dish which has a radius of curvature of approximately 40 ft and a dish diameter of 33 ft. The array provides the capability to transmit RF signals, dynamically controlled in relative angular position, or to receive RF signals over a field-of-view of approximately 42° as viewed by a sensor mounted on TARFS-1. The location of the apparent source of radiation of the RF signals is controllable to within 0.3 mrad, with a current working accuracy of at least 1 mrad.

TABLE 2. ARRAY HARDWARE PERFORMANCE PARAMETERS

	3 GHz	5.5 GHz	10 GHz	16 GHz
Power Divider (6 Way)				
Isolation – adjacent ports	17 dB	17 dB	17 dB	20 dB
Isolation – nonadjacent ports	22 dB	22 dB	22 dB	26 dB
Phase Shifter				
Phase repeatability	±3°	±3°	±3°	±3°
Insert on loss repeatability	±0.1 dB	±0.1 dB	±0.1 dB	±0.1 dB
Phase resolution	2.8° step size	2.8° step size	2.8° step size	2.8° step size
Insertion loss	2.4 dB	2.4 dB	2.4 dB	2.4 dB
VSWR* $T_r^* = 3\ \mu sec$	1.6:1	1.6:1	1.8:1	2:1
Attenuator				
Attenuation repeatability	±0.1 dB	±0.1 dB	±0.1 dB	±0.2 dB
Phase repeatability	±2.5°	±2.5°	±2.5°	±2.5°
Attenuation resolution	0.1 dB step size	0.1 dB step size	0.1 dB step size	0.1 dB step size
Insertion loss	7 dB	6 dB	6.5 dB	7 dB
VSWR $T_r = 10\ \mu sec$	1.67:1	1.5:1	1.5:1	2:1
Maximum attenuation	60 dB	60 dB	60 dB	50 dB
Switches (1st, 2nd, 3rd LEVEL)				
Phase repeatability	±2.5°	±2.5°	±2.5°	±2.5°
Insertion loss repeatability	±0.1 dB	±0.1 dB	±0.1 dB	±0.2 dB
1st level $T_r = 0.5\ \mu sec$	1.7 dB	1.8 dB	1.8 dB	2.7 dB
2nd level	1.7 dB	1.9 dB	1.8 dB	3.2 dB
3rd level	1.7 dB	1.9 dB	1.9 dB	3.5 dB

TABLE 2. (Continued)

	3 GHz	5.5 GHz	10 GHz	16 GHz
Switch (4th Level)				
Phase repeatability	±2.5°	±2.5°	±2.5°	±2.5°
Insertion loss repeatability	±0.1 dB	±0.1 dB	±0.1 dB	±0.2 dB
Insertion loss	2.2 dB	2.5 dB	3.1 dB	6.0 dB
VSWR (output ports)	1.75:1	1.75:1	1.75:1	4.5:1
Isolation	60 dB	60 dB	60 dB	45 dB
Power Combiner (4-Way)				
Insertion loss	0.7 dB	1.0 dB	1.5 dB	2.3 dB
Isolation — adjacent ports	20 dB	20 dB	20 dB	20 dB
Isolation — nonadjacent ports	26 dB	26 dB	26 dB	26 dB
Antenna				
VSWR	2:1	2:1	2:1	3:1
Cross-polarization coupling	-20 dB	-20 dB	-20 dB	-20 dB
Antenna/antenna coupling				
Antenna/ECM coupling				
TARFS-1				
Angular error — pitch and yaw	±0.5 mrad	±0.5 mrad	±0.5 mrad	±0.5 mrad
Repositioning error				
Calibration System				
Path loss calibration error	±0.1 dB or 1% reading whichever is greater	±0.1 dB or 1% reading whichever is greater	±0.1 dB or 1% reading whichever is greater	±0.2 dB or 1% reading whichever is greater
Path length calibration error	±0.3°	±0.3°	±0.3°	±1°
Angular accuracy	±0.215 mrad	±0.153 mrad	±0.084 mrad	±0.124 mrad
Amplitude imbalance	±0.1 dB or 1% reading	±0.1 dB or 1% reading	±0.1 dB or 1% reading	±0.2 dB or 2% reading
Phase Shifter calibration				
attenuation	±0.1 dB	±0.1 dB	±0.1 dB	±0.2 dB
phase	±0.3°	±0.3°	±0.3°	±1°

TABLE 2. (Concluded)

	3 GHz	5.5 GHz	10 GHz	16 GHz
Attenuator calibration				
phase	±0.3°	±0.3°	±0.3°	±1°
attenuation 0 to 21 dB	±0.1 dB or 1% reading	±0.1 dB or 1% reading	±0.1 dB or 1% reading	±0.2 dB or 2% reading
21 to 37 dB				
37 to 47 dB				
> 46 dB				
Phase baseline	15 1/2 in.	12 in.	12 in.	8 1/2 in.

*Voltage Standing Wave Ratio
**T_r = Switching Time

TABLE 3. SIMULATION FLIGHT PARAMETERS

Target Generation	Capability	Main Array
Frequency	4 to 18 GHz	42° Field-of-view
Simultaneous Targets	4 at 4 to 12 GHz, 2 at 12 to 18 GHz	4 Targets
Reference	1	Elliptical Polarization Diversity (2) Circular: $P(r < 1.4)$ 0.8 45° Linear: $P(\lvert r\rvert > 10) = 0.8$ $P(\lvert \Delta\xi \rvert < 6^\circ) = 0.9$
Scintillation	40 Hz over a 40 dB Dynamic Range	333 Hz, or 3 msec, Update
Target Velocity Capability	0 to 20,000 ft/sec	534 Elements
Relative Velocity Controllability	0.5 ft/sec with 5-Hz Jockeying	Target Accuracy:* 4 to 12 GHz: 0.3 mrad Linear Polarization
Waveforms Computer Control	Pulse, CW, CHIRP 333 Hz	0.5 mrad Other Elliptical Polarization 12 to 18 GHz:
ECM	**Capability**	1.0 mrad Linear Polarization 1.5 mrad other elliptical Polarization
		ECM Array
Stand-off Jammers	2	16 Elements of 42° Field-of-view
Examples of Denial Jamming	Spot, Swept Spot, Blinking, and Barrage Jamming	Elliptical Polarization Diversity Two Simultaneous Stand-off Jammers
Examples of Deception Jamming	Velocity and Rangegate Stealer	Fuze, Reference Signals

TABLE 3. (Concluded)

Target Generation	Capability	Main Array
J/S Ratio	Up to 50 dB (Limited, 1 kW Peak, 10-W CW)	One, 100-mW Full Modulation Reference Channel
Jammer Modulation	10% Frequency, 100% Amplitude	Hard Coupled RF Signals Uplink and Downlink Equipment Available
		Environment
		Programmable and Controllable Including Ground Clutter and Multipath

*A working accuracy of 1 mrad is generally available throughout the array in all frequencies and polarizations.

TABLE 4. ERP OF RFSS ARRAY.

Frequency (GHz)	ERP at Array (dBm)			Power Density at Seeker Antenna (dBm/m^2)	
	Modulation	Target Array	ECM Array	Target Array	EMC Array
5.5	CW	11	26	-22	-7
	PULSE	32	47	-1	14
10	CW	9	24	-24	-9
	PULSE	36	51	3	18
16	CW	-3	12	-36	-21
	PULSE	15	30	-18	-3

The nominal update rate of target parameters is 3 msec or 333 Hz. Two factors limit the update rate: the time required to run target modeling information of Mini 6 and the time required to run the fine position algorithm on Minis 1 through 4. Faster update rates will be available in 1978 by adding additional memory to Minis 1 through 4 and Mini 6 and rewriting the preceding algorithms for optimum execution time. With this modification, update rates of 1 kHz will be approached.

A. Target Position and Polarization Accuracy

"Target position" refers to the apparent phase center of radiation of a signal transmitted by the target array. Target position is measured by a sensor mounted on the TARFS-1. "Target position error" is the difference between the target position measured by a sensor and the commanded target position. Target position error varies within limits at every point on the array.

"Polarization" refers to the behavior of the electric field vector of the signal appearing at the sensor. Polarization is discussed in terms of the axial ratio and tilt angle of the polarization ellipse. "Polarization error" is the deviation of axial ratio and tilt angle from their commanded values. Like target position error, polarization error varies within limits at all target positions on the array. The system accuracy goals for target position depend on the frequency and polarization. In the 2- to 12-GHz band, the RMS target position error goal at any point on the array is that it be less than 0.3 mrad in both the azimuth and elevation directions for either horizontal or vertical linear polarization. For any other polarization, the goal is 0.5 mrad. In the 12- to 18-GHZ band, the RMS target position error goal at any point on the array is that it be less than 1.0 mrad for horizontal or vertical polarization and less than 1.5 mrad for any other polarization.

Target position and polarization accuracy defined previously are based on seeker antenna aperture diameters of 13.5 in. or less for the 2- to 12-GHz range and on seeker antenna aperture diameters of 8 in. or less for the 12- to 18-GHz range.

1. Target Position Accuracy

The actual system accuracy for target position achieved to date has met the preceding goals in a statistical sense, although some points on the array fail to meet the criteria by a few tenths of a milliradian on any daily calibration. Target position error is a function of the following:

a) Residual near-field effects.

b) Array antenna position errors.

c) Spurious radiation.

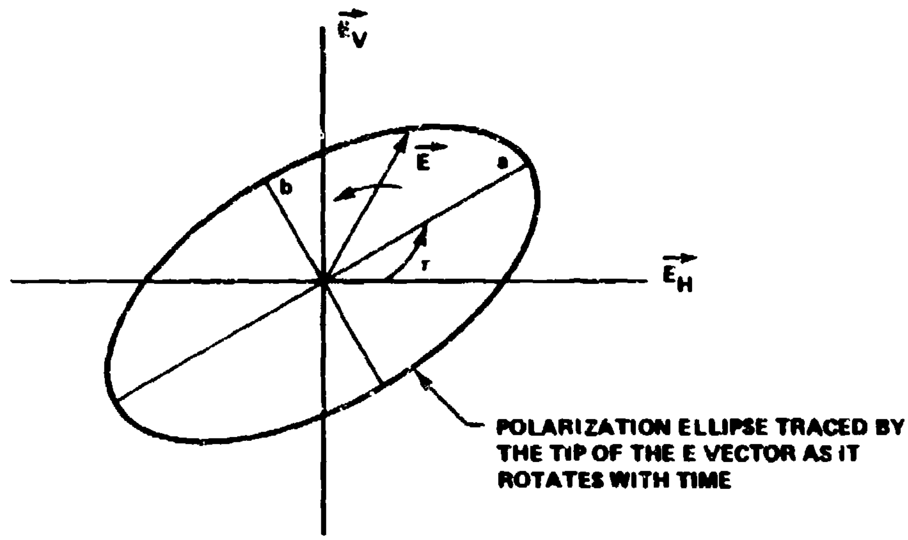
d) Phase errors.

e) Amplitude errors.

2. Polarization Control Accuracies

The polarization of an electromagnets wave refers to the behavior of its electric field vector. The most general state of polarization a wave can take is elliptical, so named because the tip of the electric field vector traces out an ellipse with time. The two parameters used to describe the state of polarization are the tilt angle (τ) and the axial ratio (r). The meaning of these two quantities is defined in Figure 14. The tilt angle is the angle which the major axis makes with respect to the horizontal. Tilt angle is restricted to lie in the range $-90° < \tau \leq 90°$. The magnitude of the axial ratio is the ratio of the major axis to the minor axis and is, therefore, always greater than unity. The range of r is $-\infty < r \leq -1$; $1 \leq r < +\infty$. The sign of r depends on the sense of rotation of the electric field vector as it traces out its ellipse. Positive values of r denote "right-hand" rotation, meaning that the fingers of the right hand curl in the direction of rotation of the electric field vector when the thumb points in the direction of propagation. Negative values of r denote "left-hand" rotation.

Polarization states of special interest occur when the axial ratio takes extreme values. When the magnitude of r approaches unity, the polarization ellipse degenerates to a circle. Such a condition is called circular polarization. There are two forms of circular polarization: right-hand circular with $r = +1$ and left-hand circular with $r = -1$. When the magnitude of r approaches infinity ($r \rightarrow \pm \infty$), the polarization ellipse collapses to a line (the minor axis shrinks to zero). In this case, it is called linear polarization; the electric field vector does not rotate, but is confined to a line.



τ = TILT ANGLE $-\frac{\pi}{2} < \tau \leq \frac{\pi}{2}$

$|r| = \frac{a}{b}$ = MAGNITUDE OF AXIAL RATIO $-\infty < r \leq -1;\ 1 \leq r \leq +\infty$

SIGN OF r = $\begin{cases} +, \text{ IF } \vec{E} \text{ ROTATES CLOCKWISE WHEN LOOKING IN THE DIRECTION OF PROPAGATION} \\ -, \text{ IF } \vec{E} \text{ ROTATES COUNTER CLOCKWISE WHEN LOOKING IN THE DIRECTION OF PROPAGATION} \end{cases}$

IF THE SIGN OF r IS +, THIS IS CALLED "RIGHT–HAND" SENSE OF ROTATION, BECAUSE IF THE THUMB POINTS IN THE DIRECTION OF PROPAGATION, THEN THE FINGERS OF THE RIGHT HAND CURL IN THE DIRECTION OF ROTATION OF THE E VECTOR. IF THE SIGN OF r IS –, THIS IS "LEFT–HAND" SENSE OF ROTATION.

Figure 14. Definition of polarization parameters.

It can be shown that any electromagnetic wave is expressible as the sum of two spatially orthogonal, linearly polarized waves. The relative amplitude and phase of the two orthogonal linear components determine the polarization of their resultant. This concept provides the basic method of polarization control in RFSS, namely, control of the relative amplitude and phase of two signals which are radiated by the two orthogonal, linearly polarized ports of any array antenna. Because the polarization depends on the relative amplitude and phase of the two orthogonal, linear components, errors in amplitude and phase control lead to polarization errors.

The RFSS polarization accuracy design goals are shown in Table 5. These accuracies are typical of those provided by target calibrations.

3. Special RF Target Generation Interfaces

Each simulation program conducted in the RFSS requires some modification or interface addition to the RF target generation equipment to provide the program peculiar target signals specified by the RFSS user. This interface can be simple, if user requirements can be generally met by existing interfaces, or complex, if the required target signals have not been generated previously by the RFSS. An example of an interface in which a jammer signal is generated for colocation on a target signal is shown in Figure 15.

IV. CONTROLS AND INTERFACES

A. Major Control and Interface Equipment

The major RFSS control and interface elements are shown in heavy lines on Figure 16. Items controlled by these elements are shown in dashed lines. Testing in the aperture rooms is, in general, under manual control, but can be patched into the master computer if required.

The primary RFSS control links are listed in Table 6. These links are discrete or analog and connect areas and equipment as shown. Figure 17 shows the layout of the equipment in the RFSS control room. The principal control equipment used by the Simulation Director during test is indicated by bold lines.

B. General Purpose Equipment

In addition to the major control and interface equipment, a supply of portable test equipment is available within the RFSS. This supply includes standard RF laboratory equipment such as signal generators, oscillators, spectrum analyzers, network analyzers, time domain reflectometers, and portable recorders. A great variety of specialized equipment is also available, with advance notice, from other MIRADCOM laboratories.

TABLE 5. POLARIZATION ACCURACY GOALS

Polarization and Antenna Coupling		3 GHz	5.5 GHz	10 GHz	16 GHz
Circular -20 dB at 180°	Axial Ratio r	$P(r < 1.4) = 0.82$	$P(r < 1.4) = 0.81$	$P(r < 1.4) = 0.78$	$P(r < 1.4) < 0.79$
45° Linear	Tilt Angle τ	$P(\lvert\Delta\tau\rvert < 6°) = 0.92$	$P(\lvert\Delta\tau\rvert < 6°) = 0.92$	$P(\lvert\Delta\tau\rvert < 6°) = 0.87$	$P(\lvert\Delta\tau\rvert < 6°) = 0.90$
-20 dB at 180°	Axial Ratio r	$P(\lvert r\rvert > 10) = 0.81$	$P(\lvert r\rvert > 10) = 0.83$	$P(\lvert r\rvert > 10) = 0.87$	$P(\lvert r\rvert > 10) = 0.82$
22.5° Linear	Tilt Angle τ	$P(\lvert\Delta\tau\rvert < 6°) = 0.74$	$P(\lvert\Delta\tau\rvert < 6°) = 0.75$	$P(\lvert\Delta\tau\rvert < 6°) = 0.72$	$P(\lvert\Delta\tau\rvert < 6°) = 0.73$
-20 dB at 180°	Axial Ratio r	$P(\lvert r\rvert > 10) = 0.92$	$P(\lvert r\rvert > 10) = 0.92$	$P(\lvert r\rvert > 10) = 0.92$	$P(\lvert r\rvert > 10) = 0.92$
22.5° Linear	Tilt Angle τ	$P(\lvert\Delta\tau\rvert < 3°) = 0.88$	$P(\lvert\Delta\tau\rvert < 3°) = 0.88$	$P(\lvert\Delta\tau\rvert < 3°) = 0.85$	$P(\lvert\Delta\tau\rvert < 3°) = 0.84$
-20 dB at 90°	Axial Ratio r	$P(\lvert r\rvert > 10) = 0.71$	$P(\lvert r\rvert > 10) = 0.74$	$P(\lvert r\rvert > 10) = 0.73$	$P(\lvert r\rvert > 10) = 0.76$

Note: The probability statements define one-sided 97.5% confidence limits.

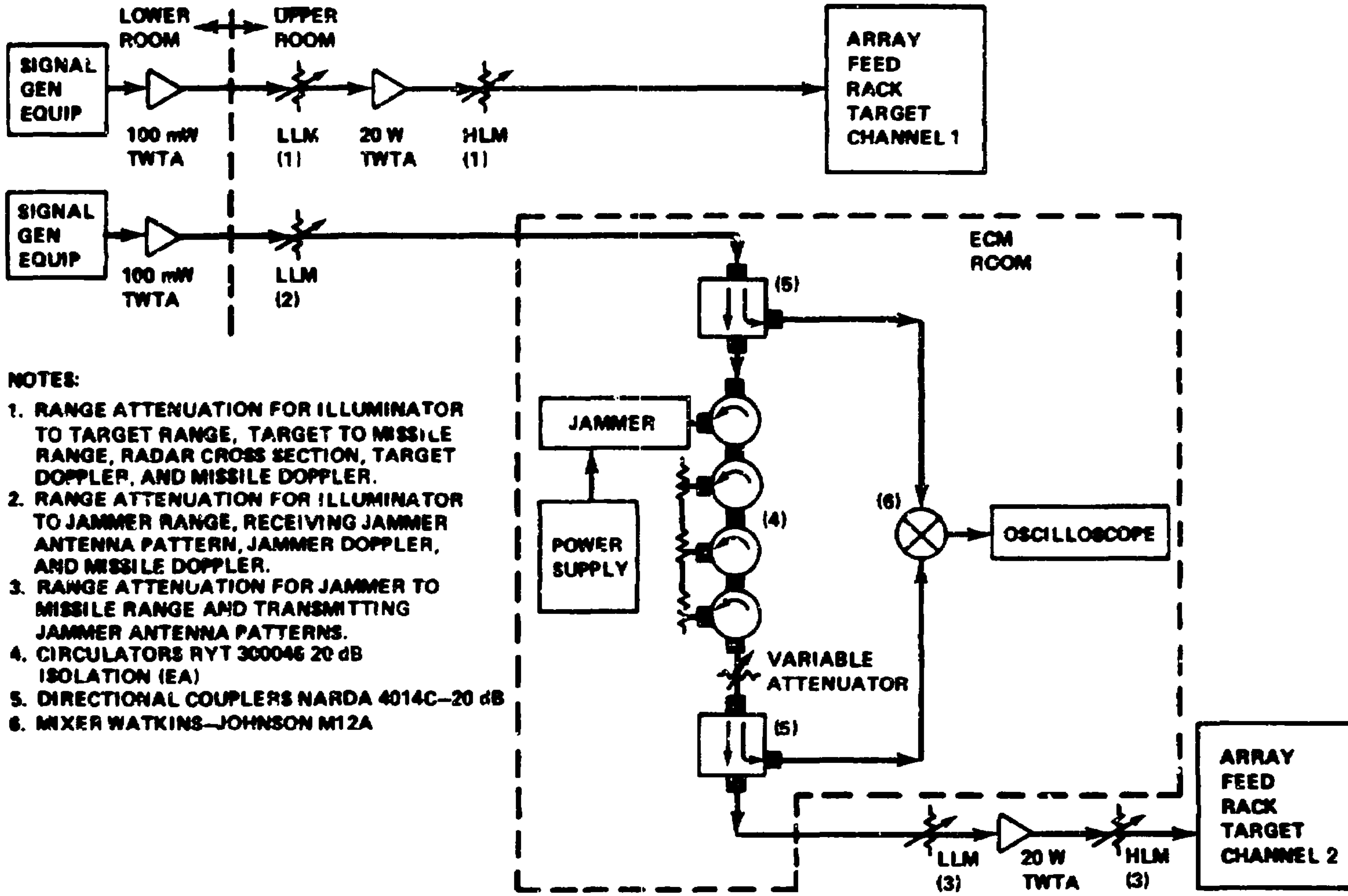


Figure 15. Typical RFSS, RF interface for jammer and target integration.

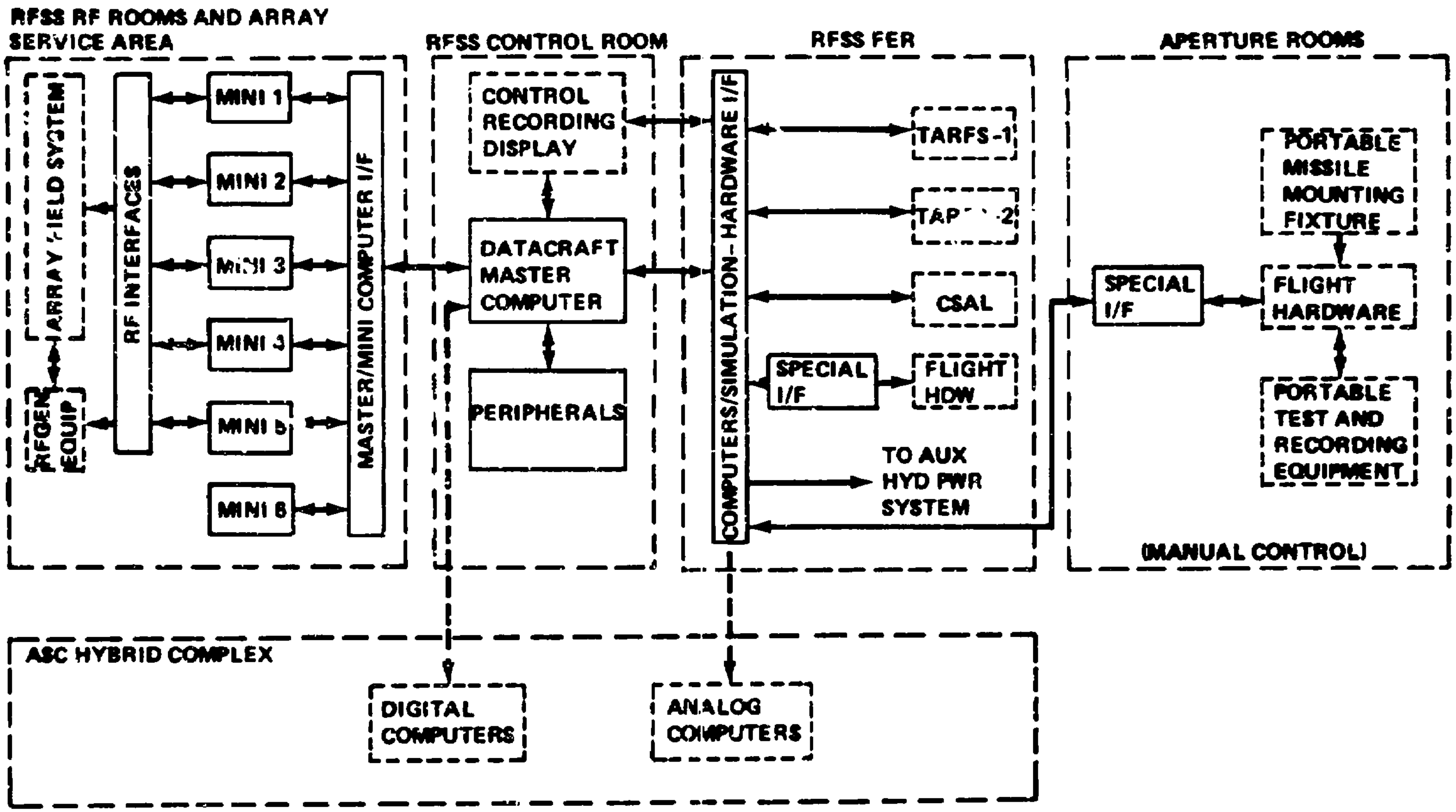


Figure 16. RFSS control and interface elements.

TABLE 6. RFSS CONTROL LINKS

Area	Discrete	Patchable to	Analog	Patchable to
Flight Equipment Room	96 Channel 0 to +5 Inputs Command 96 Channel 0 to +5 V Output Command	Datacraft	64 Channel ±10 V Output 64 Channel ± V Inputs	Analog Room
	32 Channel 0 to +5 V Inputs Command 32 Channel 0 to +5 V Output Command	Analog Room	24 Channel ±10 V Outputs	Datacraft

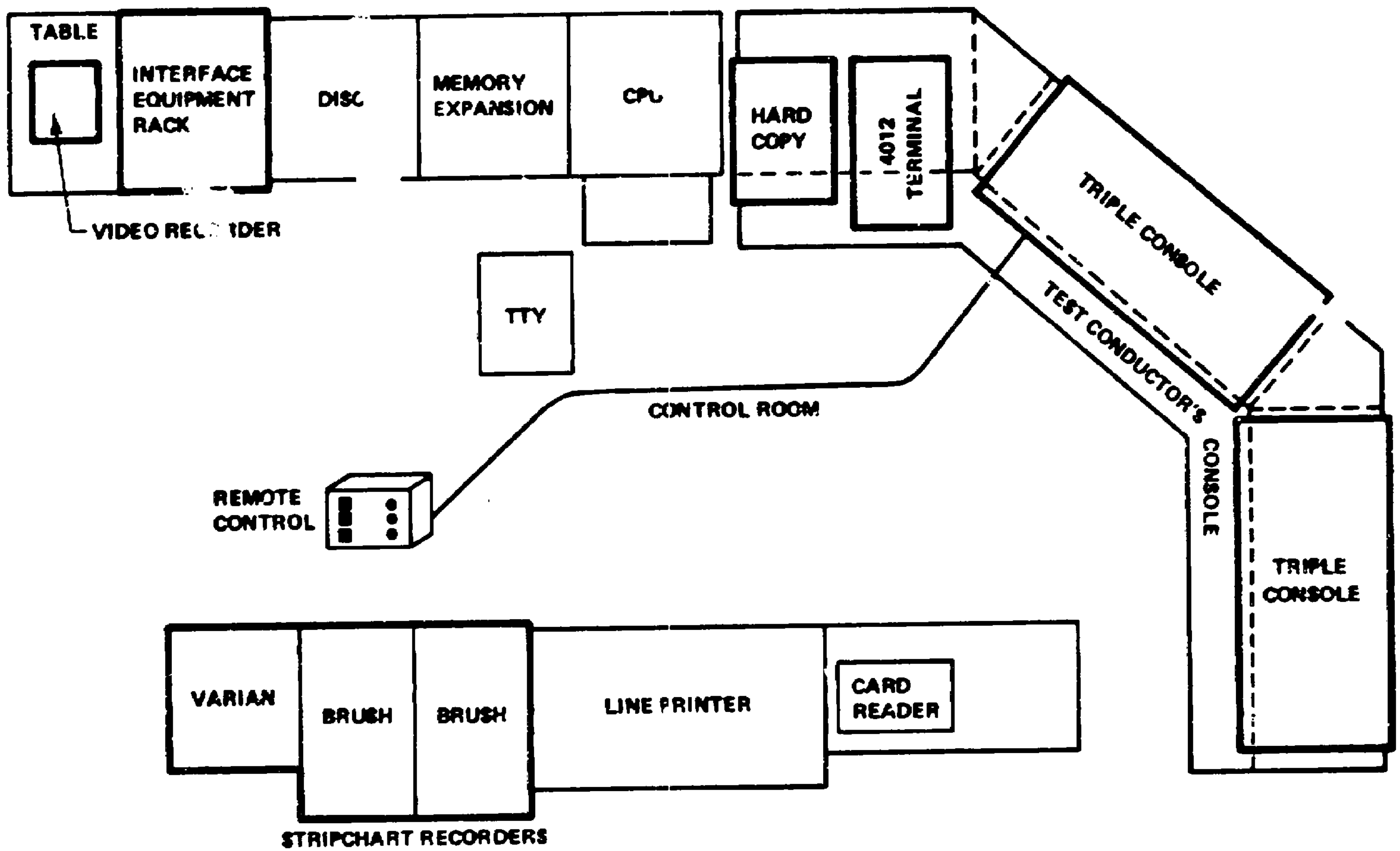


Figure 17. RFSS control room layout.

C. Interface Equipment

For each simulation program conducted at the RFSS, special interface equipment is required. An interface is required for the flight hardware to interface with the RFSS equipment in the FER. This interface provides data and control access to the flight hardware and may be designed and developed entirely by RFSS engineers or may be built around an existing control panel or test set supplied by the RFSS user. The FER interface may also be used in the aperture rooms if testing is conducted there prior to FER testing. A second special interface is required for the RF generation equipment to assure that the target signals generated have the proper signature and characteristics and/or to integrate jamming equipment into the RF generation chain. Early identification of the requirements for these interfaces as well as the I/O requirements for test control, recording, and display parameters are required to implement a successful RFSS program. Additional interface equipment such as missile holding fixtures as well as modification to the RFSS permanent equipment may also be required.

Each piece of interface hardware developed for a specific program goes through a development and integration effort. Although there is no standard level of effort, as each program tends to be unique, the development and integration steps are standard:

a) Definition of functional requirements.

b) Developmenmt and review of a design concept.

c) Detail design (drawings and parts lists).

d) Release of requests for procurement.

e) Receive, expedite, and inspect parts.

f) Assemble drawer(s)/cable(s).

g) Check out and integrate drawer(s)/cable(s).

h) Integration of the program specific hardware with the RFSS and with the RFSS and with the software.

D. Computers

Computer control of the RFSS is provided by a Datacraft 6024/1, five Interdata Model 80, and one Interdata Model 85 computers. The location and interconnection of these computers are shown in Figure 16. The basic capabilities of these computers are shown in Tables 7 and 8. Two fixed-head disc storage units are available with the Data craft computer. The capabilities of the discs are shown in Table 9.

TABLE 7. DATACRAFT 6024/1 CHARACTERISTICS

Feature	Capability
Memory Size	32,768 Words
Word Size	24, Bits Plus Memory Parity
Registers	5-24 Bit (3 may be used for indexing
Addressing (Direct, Indirect and Indexing)	32,768
Cycle Time	600 nsec
I/O Capability	
ABC Channels	8 Provided (UP TO 14 Possible)
Standard Channel	1 Provided (UP TO 28 Possible)
Priority Interrupts	
Internal	8 (Standard)
External	24
Sense Switches	4
Central Processing Unit (CPU) Features	
Power Fail Shutdown and Restart Program	
Restrict/Instruction Trap	
Stall Alarm	
Interval Timer	
Address Trap	
Scientific Arithmetic Unit (Floating Point)	
Bit Processor	
Hardware Bootstrap	

Additional computing and data storage capability is provided through data links with the ASC CDC 6600 digital computer, the EAI 781 computer and the AD-4 analog computer. Real-time operation with the control computer complex in the loop is available if required.

E. TARFS and CSAL

The capabilities of the TARFS-1 and TARFS-2 and the CSAL which simulate the flight rotational motions and the aerodynamic load environment of missile flight hardware during real-time testing are shown in Table 10. The TARFS-1 is used for the seeker; the TARFS-2, with a higher frequency response, is used for the autopilot.

TABLE 8. BASIC FEATURES OF INTERDATA MODELS 80 AND 85 COMPUTERS

Feature	Capability
Instruction Repertoire	127 Instr. Including Multiply/Divide Both Fixed and Floating Point (131 Instr. for Model 85)
Instruction Work Format	Full Word (32 Bits) and Half Word (16 Bits)
Direct Accessing	65,536 Bytes
Data Work Length	8, 16, and 32 Bits
Memory Size	16K Bytes
Accessing Time	332 nsec
General Registers	16 (15 Usable for Index Registers)
Priority Interrupts	8 (External)
Input/Output	Via Selector Channel (DMA) (Two Provided) (Separate Teletype I/O)
Additional Model 85 Features:	
Micro Processor:	
Micro Instructions	170
Control Store Memory (Fixed)	4096 Bytes 60 nsec Access
Control Store Memory Dynamic	4096 Bytes 200-nsec Access
Data Work Length	16 Bits
Universal Clock:	
Resolution	1, 10, 100, and 1000 μsec (Intervals)
Program Control	Command, Status, Count, Interval

F. RFSS Instrumentation

The major elements of RFSS permanent instrumentation and display capability are listed with their location in Table 11. Additional recording and display equipment is available through patching to the hybrid computer room or by employing portable equipment.

TABLE 9. FIXED-HEAD DISC SPECIFICATIONS

Feature	Specification
Rotational Speed	1800 rpm
Average Access Time	16.7 msec
Transfer Format	Serial
Transfer Rate	134,400 words/sec
Storage	143,360 words
Number of Heads/Track	1
Number of Tracks	32
Words Per Sector	112 plus End of Sector word
Sectors Per Track	40

V. SOFTWARE

Computer control of RFSS checkout and operations is provided by approximately 50 special propose programs. These programs control all target and test manipulations and provide for automatic data reduction. When required by specific tests, auxiliary software programs are developed and/or existing programs are modified by the RFSS software staff. RFSS software is divided into simulation independent and simulation dependent programs.

A. Simulation Independent Software

Simulation independent software includes calibration programs, diagnostics, Tektronix display, and portions of the simulation logic. Calibration software, for example, provides automated calibration of both the array and RF generation equipment at the user's designated frequency. Diagnostic programs are run on all equipment in a particular simulation configuration. This software isolates hardware malfunctions and minimizes the effort to repair the malfunction. Simulation logic that is considered simulation independent includes the Target Control Algorithm and RF Generation Control Algorithm. These are Interdata computer programs which compute command words to control the array and RF generation equipment per simulation-dependent data supplied by Datacraft computer.

TABLE 10. TARFS AND CSAL PERFORMANCE SUMMARY

TARFS-1 Specifications:

Load limitations:
Load size: 16-in. diameter, 60-in. long
Load weight: 150 lb

Performance characteristics

	Pitch/Yaw	Roll
Angular Displacement	±50 deg	±50 deg
Load Inertia	15 slug-ft^2	1.5 slug-ft^2
Position accuracy	±1.0 mrad	±1.0 mrad
Repeatibility	±0.1 mrad	±0.1 mrad
Velocity	200 deg/sec	400 deg/sec
Acceleration	900 deg/sec^2	40,000 deg/sec^2
Frequency Response	13 Hz	30 Hz

TARFS-2 Specifications

Load Limitations:
Load Size: 10-in. diameter, 10 in. long
Load Weight: 50 lb

Performance Characteristics

	Pitch/Yaw	Roll
Angular Displacement	±80 deg	±50 deg
Load Inertia	0.042 slug-ft^2	0.042 slug-ft^2
Position Accuracy	±0.1 mrad	±1.0 mrad
Repeatability	±0.1 mrad	±0.1 mrad
Velocity	200 deg/sec	700 deg/sec
Acceleration	40,000 deg/sec^2	200,000 deg/sec^2
Frequency Response	30 Hz	80 Hz

CSAL Specifications

Parameter	Characteristics
Load Size (diameter)	From 3 to 24 in.
Torque Output (maximum)	±1000 ft-lb
Rotational Displacement	±45 deg
Load Inertia	0.02 slug-ft^2
Position Accuracy	±0.05 deg
Torque Accuracy	± ft-lb
Maximum Velocity	700 deg/sec
Frequency Response	50 Hz

TABLE 11. RFSS FACILITY INSTRUMENTATION

Location	Recording	Display
Control Room	Varian Status IV Electrostatic Recorder with 16 Analog Channels and 10 Discrete Events	TEK 613 Graphic Display TEK 4012 Terminal/Graphic Display
	Two Brush Model 200 8 Analog with Channel Strip Chart Recorder	Two Closed Circuit TV Monitors
	TEK 4610 Hard Copy Unit Multiplexed to TEK 613 and TEK 4012 Displays	Facility EMI Integrity Status
	Sony AV-3650 1/2-in. Video Recorder	Hydraulic and RF Generation Hardware Integrity Status
	Direct Digital Link to Adjoining CDC 6600 Room Giving Access to Magnetic Tape and Disc as well as Standard Peripheral Recording	RF Spectrum Display Unit RF Power Display RF Frequency Display
	CDC Line Printer	
Flight Equipment Room Tustin X-1500 ADC-12 128 Channel	FR1900 Analog Tape with 14 Channels Available (7 Direct Record and 7 FM Record)	Closed Circuit TV Monitor
Lower RF Room	Brush Model 200 Strip Chart Recorder with 8 Analog Channels	RF Spectrum Display RF Power Display
	Tridata Cartrifile	RF Frequency Display
East and West Aperture Rooms	Varian Electrostatic Recorder with 8 Analog Channels and 10 Discrete Events	Portable Test Equipment as Required

B. Simulation Dependent Software

Simulation dependent software must be developed specifically (or modified) for both open-loop and closed-loop programs. There currently exists a set of open-loop, or seeker characterization, subroutines. They control both target position and RF generation parameters such as power, Doppler, and range delay. Modification of these routines is usually required to meet the specific requirements of the user's test plan. Existing closed-loop software includes Executive Control, Missile Model, RF Model, Relative Geometry, and I/O Handling. Simulation dependent software is required in each of these areas to implement a specific program. The amount of effort to adapt existing closed-loop software to a user's requirements is a function of the missile characteristics as well as the user's test plan.

The Missile Model, a major simulation dependent effort, may be developed to run internally within the RFSS on the Datacraft computer if not too complex or may be provided externally from the ASC hybrid computer complex for more complex models. The RF Model, also a major simulation dependent effort, includes the target scenario and control of RF generation equipment. The target trajectory is implemented by inputting acceleration commands versus time. A number of maneuver tables have been developed, including sine weave and split S. Other maneuvers are developed as requested by the user. The Relative Geometry Model provides the coordinate transformations and calculations necessary to determine the geometric parameters between the Missile Model and the RF Model. Significant modification of the Relative Geometry Model is usually required to implement a specific simulation. I/O handling involves computer control of all hardware in the RFSS facility. Modification of existing RFSS hardware by the user requires a corresponding software modification.

C. Software Test Program Support

Test programs in the RFSS facility are conducted in five phases as follows:

1) Coordination and planning.

2) Development.

3) Integration and checkout.

4) Test.

5) Documentation.

Simulation dependent software and support by the software staff are required in the last four phases. In the development phase, simulation dependent software must be generated to support the user's specific requirements for missile/target kinematics and RF control. In order to implement these software requirements for a user's program, early identification by the user of his test matrix, I/O; interface; and control, recording, and display requirements are needed. The test matrix provides a list of the tests the user requires; through a discussion of this matrix, the relative engagement requirements are derived. These are first expressed in geometric equations of motion by the RFSS Systems Engineer to establish a relative geometry model as well as a dynamic target signature model to define the complete engagement scenario. The software staff then implements these model in software to provide control of target/missile relative geometry and RF generation.

The software staff then participates in the hardware/software checkout phase which precedes the actual test. During the test phase, the software staff provides support to assure that the missile/target motions and target signatures are controlled as required by the Simulation Director.

In the documentation phase, special software programs are often required to reduce the large volume of data that can be generated by the multi-run, statistical data complilation. If these data were not reduced automatically, they would be unmanagable.

D. RFSS Software Programs

The major software programs currently available in the RFSS are as follows:

1) Subsystem Tests.

a) Peripheral Tests.

(1) Datacraft Peripheral Test.

(2) Model 80 Interdata Peripheral Test.

b) Control Console Test.

c) Interface Readiness Test — Equipment Interface Readiness Test.

d) Interface Tests.

(1) Master/Mini Interface Test.

(2) RF Generation Interface Test.

(3) Array Interface Test.

e) Array Calibration Unit Test.

f) Strip Chart Recorder Test.

g) TARFS Readiness Test.

h) CSAL Position Test.

i) RF Generation Test.

j) Master Sync Test.

k) Calibration Sensor Test.

2) Calibration and Alignment Programs.

a) Array Alignment Program.

b) Path Loss/Path Length Calibration Program.

c) Path Loss/Path Length Mapping Program.

d) Attenuator/Phase Shifter Calibration Program.

e) Attenuator/Phase Shifter Readiness Test.

3) System Demonstration Programs.

a) Polarization Diversity Test.

b) Target Accuracy Test.

c) Open-Loop Test.

d) Closed-Loop Simulation.

e) Simulation Executive Control Program.

f) ECM Array Control Test.

4) Simulation Aids.

a) Datacraft — Real-Time Graphics Program.

b) Interdata.

(1) Target Control Program.

(2) ECM Control Algorithm.

(3) Polarization Control Algorithm.

(4) Coarse-Position Control Algorithm.

(5) Fine-Position Control Algorithm.

(6) RF Generation Algorithm.

(7) Noise Algorithm (Glint, Scintillation).

5) Special Programs.

a) Test Directory Initializor.

b) Test Directory Editor.

c) Fast Fourier Transform.

d) Master/Mini Interface Diagnostics.

e) Tektronic Graphics Diagnostics.

f) Near-Fields Effects Correction Table Program.

g) Low/High Level Modulator Calibration Program.

h) FR 1900 Test.

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